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References to literature, arranged alphabetically according to authors' names, should be placed at the end of the article, the various references to each author being arranged chronologically. Each reference should contain the name of the author (with initials), the year of publication, title of the article, the abbreviated title of the publication, volume and page. In the text, the reference should be indicated by the author's name, followed by the year of publication enclosed in brackets; when the author's name occurs in the text, the year of publication only need be given in brackets. If reference is made to several articles published by one author in a single year, these should be numbered in sequence and the number quoted after year both in the text and in the collected references.

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(February 1943)

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ORIGINAL ARTICLES

THE COTTON BOLLWORMS (*EARIAS FABIA* STOLL., *PLATYEDRA GOSSYPIELLA* SAUND. AND *HELIOTHIS OBSOLETA* FABR.) IN THE CENTRAL PROVINCES AND BERAR*

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(Received for publication on 14 August 1939)

IT was observed by the Entomological Section, Central Provinces Department of Agriculture, that considerable damage was done to cotton by the boll-worms but on account of paucity of staff it was not possible to undertake any detailed investigation on these pests. The sporadic attempts to study the problem and occasional observations made on the subject departmentally did not furnish sufficient data on which to base definite conclusions. A specific scheme for investigation into the bollworm problem was, therefore, started with the funds provided by the Indian Central Cotton Committee. The scheme commenced in July 1934 and terminated in September 1937. The junior author who had worked in the Broach Clean-up Scheme was appointed as Assistant and the work was carried out under the supervision and guidance of the senior author.

The final report of the scheme was submitted to the Indian Central Cotton Committee in May 1938 and the Committee recommended its publication subject to unimportant portions being deleted. This work of deletion was done by the junior author.

The paper, however, still required considerable revision and redrafting which have been carried out by Mr K. R. Sontakay, the present Entomologist to Government, Central Provinces and Berar.

The financial help given by the Indian Central Cotton Committee is gratefully acknowledged.

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*Final Report of the Central Provinces and Berar Entomological Scheme financed by the Indian Central Cotton Committee 1934-37

The pink bollworm (*Platyedra gossypiella* Saund.) and the spotted bollworm (*Earias fabia* Stoll.) were known as serious pests of cotton in the Central Provinces and Berar as in other cotton areas of the country, but as no detailed work on them was done the 'Central Provinces and Berar Entomological Scheme' was sanctioned with the object of ascertaining the distribution of the bollworms in the province, their incidence, extent of damage and the means of 'carry-over' from one season to another. Further, the Indian Central Cotton Committee desired that investigation should be undertaken to explore the possibility of applying the results of researches of the Surat Bollworm Scheme to the problem relating to this province. Nagpur was selected as centre for work in the Central Provinces and Akola in Berar.

During the course of investigation it was observed that a third bollworm, i.e. *Heliothis obsoleta*, commonly known as the American bollworm of cotton was also responsible for some damage during the early part of the cotton season. During the final year of the scheme work was mainly concentrated on this insect. The results of investigations are embodied in this paper.

Soil and climate of the cotton tract

Soil

The soil of the cotton tract of the province is typically clayey loam. It is deep black in colour, subject to waterlogging during continuous heavy rains. Cracks begin to appear soon after the monsoon and these gradually widen till in summer they are as deep as 30 inches.

Rainfall and humidity

Monsoon breaks in the second or third week of June and during July and August the rainfall is heavy. The annual rainfall varies from 28 in. to 32 in. in Berar and from 35 in. to 45 in. in the cotton tract of the Central Provinces. After the rainy season, humidity begins to fall gradually. In the month of May the air becomes very dry and the percentage of moisture is as low as 19 (Appendix I).

Temperature

The climate of the cotton tract is, on the whole, hot and dry with a mild winter. The minimum temperature rarely goes below 56°F. during December and January. From February, the temperature rises and in May, which is the hottest month of the year, it varies between 110°F. and 115°F. and sometimes goes to 118°F. During the monsoon the mean temperature varies in the neighbourhood of 80°F.

The life of cotton crop in the Central Provinces and Berar

Seed is sown generally in the last week of June or the first week of July after a few heavy showers of rain. The bolls burst in the latter half of October or in early November. Usually pickings are carried out till the end of December but if the rainy season is a prolonged one they are continued till the end of January. The life of the cotton crop in the Central Provinces and Berar covers a period of about 26 weeks from the time of sowing to the last picking.

The cotton grown in this province belongs to the '*neglectum*' group and is mixed with Buri (American cotton) to a certain extent. There is little or no monopodial growth in these types of cotton.

Incidence of bollworms

Observations carried over three successive seasons, 1934-37, indicate that three types of bollworms, viz. the spotted bollworm (*Earias fabia* Stoll.), the pink bollworm (*Platyedra gossypiella* Saund.) and the American bollworm (*Heliothis obsoleta* Fabr.) cause considerable damage to the cotton crop in this province.

In order to determine the incidence of the bollworms all the reproductive forms from a fixed number of plants were picked and examined. The number of different bollworms found and of the forms damaged by them was recorded.

TABLE I

Bollworm population in cotton seedlings 3 in.-18 in. high

Locality	Month and year of examination	Variety	Number of seedlings examined	Number of species of larvae found	
				E. fabia	*H. obsoleta*
Akola .	July 1935 .	Verum . .	500	2	0
		Buri . .	500	7	4
	August ,, .	Verum . .	12758	11	0
		Buri . .	3231	13	7
	June 1936 .	Verum . .	271	0	0
	July ,, .	Verum . .	2973	5	0
		Buri . .	868	0	0
	July 1937 .	Buri . .	2400	17	0
		Verum . .	2800	6	0
		L. Verum .	1000	1	0
	August ,, .	Verum . .	800	1	0
Nagpur .	July 1936 .	L. Verum .	27274	21	0
	August ,, .	L. Verum .	59955	44	0
	July 1937 .	Verum. .	4546	2	0
		Buri . .	397	0	0
	August ,, .	Verum . .	2708	8	0
		Buri . .	1413	20	0
		Roseum . .	1200	14	0
		L. Verum .	1000	1	0

It will be seen from the above table that the spotted bollworm appears in July and does a little damage to seedlings. It is the Buri variety which suffers more than others. In the seedling stage infestation by *H. obsoleta* is practically negligible.

Though the spotted bollworm appears on the cotton crop in the last week of July its progress is retarded due to heavy rains during August and September. From October, it multiplies rapidly and remains active till the end of the season. Thus there is coincidence of the increased bollworm population with the boll formation and consequently the damage is very great (Appendix II).

The pink bollworm makes its appearance on the crop in the latter half of September and gradually increases in number during the next two months. In December it multiplies rapidly till in January almost every boll is infested

by it. *Heliothis obsoleta* makes its appearance on the cotton crop at Akola in the last week of July in small numbers. The attack starts on exotic varieties. The pest gradually multiplies and is at its maximum from the beginning of September to the middle of October. At this time *tur* (*Cajanus indicus*) begins to bear pods and this crop being more favoured the insect moves on to it. *Tur* is commonly grown in the neighbourhood of cotton fields and sometimes in the same field in between eight to ten rows of cotton.

Nature and extent of damage by the bollworms

The spotted bollworm is found in the tender shoots during the last week of July when the plants are 6-9 in. in height. The larvae bore into the shoots which droop down and wither. The growth of the plants which are bored to a depth of 3-4 in. is arrested, whereas those bored to a depth one or two inches continue to grow as the development of the axillary buds is stimulated. The damage to the top shoots is one per cent and consequently the crop does not suffer any appreciable loss at this stage. Thinning of cotton during July removes some of the larvae but this is hardly an effective check as the operation is done irregularly. The larva immediately after emergence from the egg does not directly feed on the nearest available food but wanders about and then bores in the tender shoot, bud or boll. With the development of buds and bolls the damage is restricted to these forms only. The larva even before it is full grown moves on to other buds or bolls and causes similar damage. In this way it damages many more forms than are actually needed for its full growth.

During the early stage of the crop the larvae of *Heliothis obsoleta* feed on the tender shoots and leaves, but with the development of buds and bolls these are preferred. The caterpillar is a voracious feeder and is capable of finishing a boll of the size of or even bigger than an areca nut in a day. The larva thrusts its head inside the bud or boll and feeds on the entire inner contents. Tender bolls are preferred to older ones.

During the year 1935-36, a group of 500 plants was reserved at Akola to study the problem of bud and boll shedding due to bollworms and to determine the proportion of forms shed due to insect damage to total forms borne by the plants. Daily examination of the shed forms was carried out from the beginning of September till the end of January. The shed material consisted of 2220 buds, 2354 small bolls, 331 medium bolls, 135 big bolls and 125 open bolls. The percentage of damage caused by the three bollworms is given in Table II.

Table II

Percentage of forms shed due to different bollworms

Shed due to	Buds	Small bolls	Medium bolls	Big bolls	Open bolls
Spotted bollworm . .	17·0	22·7	30·8	44·4	46·7
Pink bollworm . .	0·5	0·7	4·0	10·0	10·0
American bollworm . .	33·4	14·0	15·0	5·2	..
Other causes . . .	49·1	62·6	50·2	40·4	43·3

The big-sized bolls attacked by bollworms which do not drop open prematurely. One or two locks of such bolls are partly or completely damaged. To estimate the amount of damage, *kapas* (seed cotton) from ¼ acre at Akola Farm and ½ acre at Nagpur Farm was examined during 1935-36 (Table III).

TABLE III

Percentage of damaged kapas *in* kapas *of different pickings*

Date of picking	Percentage of undamaged *kapas*	Percentage of *kapas* partly damaged by			Percentage of *kapas* completely damaged by		
		S.B.W.	P.B.W.	O.C.	S.B.W.	P.B.W.	O.C.
			Akola				
4 Nov. 1935	89·70	4·00	1·40	2·20	1·90	0·60	0·03
15 ,, ,,	85·60	7·60	2·00	2·40	1·90	0·40	0·02
29 ,, ,,	62·70	30·10	2·20	1·40	3·60	0·02	0·01
20 Dec. ,,	61·10	20·10	6·60	2·70	6·80	1·40	1·20
15 Jan. 1936	52·90	22·70	7·66	5·77	8·10	1·30	1·45
On the whole	73·40	16·00	3·20	2·40	3·70	0·60	0·50
			Nagpur				
5 Nov. 1935	91·90	1·10	0·60	1·70	2·10	0·80	2·20
18 ,, ,,	93·19	0·85	0·25	0·80	2·80	0·27	1·05
5 Dec. ,,	95·70	1·70	0·10	0·20	1·70	0·10	0·40
2 Jan. 1936	91·10	3·10	0·13	0·44	2·50	0·30	2·30
On the whole	93·80	1·60	0·23	0·66	2·30	0·20	1·20

S.B.W. = Spotted bollworm ; P.B.W. = Pink bollworm ; O.C. = Other causes

LIFE-CYCLE

Spotted bollworm

The life-history and habits of the spotted bollworm in this province are more or less the same as in other cotton tracts of India. The incubation period varies from three to five days depending on the season, shorter time being required during summer. Larval stage lasts from 15 to 18 days during December and January and 10 to 14 days during other months. Pupation takes place generally in the soil either in cracks or under clods. During May 1936, 3641 empty cocoons of the spotted bollworm were recovered from cracks

over an area of half an acre. Some cocoons were found as deep as 20 inches. The pupal period is about 16 days during winter and about nine days during the rest of the year. The maximum duration of the life of the adult is 36 days in captivity. Experiments conducted to study the egg-laying capacity of the moths showed that the maximum number of eggs laid by a female was 592 and this number was laid in 23 days. The period when most egg-laying occurred was November to February when generally over 300 eggs were laid by a female. The insect does not hibernate or aestivate but breeds continuously.

Pink bollworm

The incubation period is four to five days during all the months except December and January when it extends to seven days. The larval stage during the period from September to the end of November ranges between 10 and 14 days and in December and January 14 and 22 days. From the middle of November a few larvae enter the long-cycle stage. With the advance of the season larger number enter the long-cycle stage. Till the end of April, however, the short-cycle larvae are noticed on the standover crop. No pink bollworm is found in the crop after this period as there is no green boll on the plant. At Nagpur, the short-cycle larvae were not seen during June and July but there is some evidence to show their existence during these months at Akola (Table IX).

The pupal stage lasts for seven to nine days except in December and January when it occupies 10 to 12 days.

The duration of the life-cycle varies, in the case of the short-cycle, from 31 to 41 days during the coldest part of the year and from 20 to 28 days during the rest of the year ; and in the case of the long-cycle, from eight to nine months.

Experiments carried out to find out the longevity of the moths showed that one female fed with sugar solution lived for 51 days and laid 205 eggs during her life. Another moth which lived for 31 days laid 343 eggs. Egg-laying occurs on a large scale from November to the end of February.

According to Ballard [1923], long-cycle pink bollworm larvae do not occur in south India. Husain, Bindra and others [1931] have definitely established that in the Punjab there are two types of life-cycles of *Platyedra gossypiella* Saund., the one in which the caterpillars immediately pupate at the end of their feeding period—the short-cycle ; and the other in which the caterpillars when full fed do not pupate but pass through a prolonged period of hibernation—the long-cycle. In that province even when a fairly large supply of flower buds and green bolls was made available during May and June, no pink bollworm larvae could be found and that the first brood of 'worms' appearing in the cotton fields was the progeny of moths emerging in July and the beginning of August.

The pink bollworm seems to be capable of adapting itself to different environments. In south India there is no long-cycle stage as in the Punjab and the United Provinces. In the Hyderabad State it is found to attack early forms to an appreciable extent, whereas in the Punjab and the United Provinces this is not the case. In these provinces larger number of long-cycle larvae are found in the seeds whereas in Hyderabad they are in the soil.

'Carry-over' of the bollworms

In the Central Provinces and Berar, the last picking of cotton is finished by the end of December in normal years but in exceptional seasons it may extend to the end of January. The new crop is sown during the last week of June or the first week of July. There is thus a clear gap of five to six months between the close of one season and the commencement of the next. The bollworms have to tide over a long period when their food is either scanty or wanting. It is, therefore, necessary to know how they pass this critical period.

Spotted bollworm

After cotton is harvested, the crop is allowed to stand for a considerably long period. This induces fresh growth and numerous buds and bolls appear till the end of April, which serve as food to spotted and pink bollworms and enable them to pass the period from January to April.

The time and method of removing the cotton stalks vary in different localities. In some places they are removed by hand pulling, in others, by cutting with a sickle or harrowing or ploughing. This is ordinarily done during February and March. At places during years of heavy rainfall the stalks are deliberately allowed to standover till the end of April for harvesting the *kapas* (seed cotton) of the second flush, known as '*faldari kapas*'. This practice, however, is in vogue in some parts of Berar only. The fields are ploughed by the end of May. Observations made by allowing the crop to standover during summer show that a fair number of bollworms harbour in the plants till the end of May but during June they practically disappear (Table IV).

Table IV

Bollworm population in standover crop

Locality	Month and year of examination	No. of plants examined	Total No. of buds and bolls examined	Number and species of larvae found		
				Earias fabia	*P. gossypiella*	*H. obsoleta*
Akola	January 1935	100	392	6	38	0
	March ,,	100	589	12	32	0
	April ,,	500	2560	196	27	0
	May ,,	600	2376	76	1	0
	June ,,	150	107	1	0	0
	February 1936	450	5840	125	277	0
	March ,,	750	7170	135	617	0
	April ,,	600	3815	258	430	0
	May ,,	1500	5782	128	4	0
Nagpur	January 1935	200	1696	69	15	0
	February ,,	400	3969	214	26	0
	March ,,	500	5837	447	164	0
	April ,,	400	1619	220	39	0
	May ,,	400	1142	105	1	0
	June ,,	100	148	12	0	0

Ordinarily food is not available in the cotton fields during May and June. It can be concluded that the cotton fields do not appreciably help the spotted bollworm in tiding over the critical period.

Alternative food plants

In the cotton tract of the province elaborate irrigation facilities do not exist, but there are tanks or wells from which water is taken to raise a few vegetable and garden plants. In these places the food plants such as *bhindi* (*Hibiscus esculentus*), *ran-bhindi* (*Hibiscus panduriformis*), *ambadi* (*Hibiscus cannabinus*), *kandhi* (*Abutilon*), hollyhock (*Althaea rosea*) and *deokapas* or perennial cotton are found. Examination of these alternative food plants carried on during March to August 1935 and March to May 1936 showed that in *bhindi* and tree cotton infestation is carried over and a few specimens are found in *Abutilon* and *A. rosea* but in others the pest is practically absent. *Bhindi* is grown in summer in the vicinities of towns and villages for vegetable purposes. It is also imported from outside the province during the months of June and July. Examination of this material revealed the presence of the spotted bollworm. It is, therefore, quite possible that summer *bhindi* serves a fruitful source of reinfestation of the new crop.

The pink bollworm

In order to determine the various sources of reinfestation by the pink bollworm to the new cotton crop, a study of all possible sources such as soil, seed, *kapas*, stored cotton sticks, volunteer cotton plants and alternative host plants was made. The results are summarized below.

Examination of soil

For this purpose cotton stalks over half an acre area were removed before the first week of April in the year 1936. In May this area was dug uniformly up to a depth of 20 in. and at places where cracks were deeper up to 30 in. and the soil was carefully examined after sifting. 3641 empty cocoons of the spotted bollworm and 354 pink bollworm caterpillars were found. Out of these 354 caterpillars, 304 were found in flimsy cocoons either with fine grains of soil around them or in a wrapping of petals of withered flowers fallen on the ground. Fifty larvae were found in a free or naked state. No larva was found in the loose soil of the mulch of the top layer. Table V shows the number of larvae found at different depths.

TABLE V

Number of pink bollworm larvae found in different layers

Depth of layers in inches	1-5	6-10	11-15	16-20	21-25	No. of larvae caught in sieve	Total
No. of pink bollworm larvae found	9	45	133	15	1	151	354

While digging the soil 3½ lb. of damaged *kapas* was gathered from the cracks and burrows of rats. A careful examination of this *kapas* did not disclose any pink bollworm larva.

There is no direct evidence to say that these caterpillars succeed in emerging as moths and reinfesting the new cotton crop. The fact, however, that the pink bollworm larvae are found on stray volunteer cotton plants during June to August (Table IX) leads one to believe that possibly some of the larvae resting in the soil develop into moths in the beginning of the monsoon.

Examination of kapas

To determine the number of larvae resting in the *kapas* picked from time to time, some quantity of it was taken from the lots harvested in November, December and January. It was examined by spreading the lint. All the pink bollworm larvae found in the lint were removed and the number recorded. The *kapas* was then ginned and the seed examined by cutting. The examination of *kapas* was done over two seasons, 1934-35 and 1935-36 (Table VI).

TABLE VI

Number of pink bollworm larvae in unginned kapas

Nagpur					Akola				
Date of picking	Quantity of *kapas* examined in lb.	Period of examination	No. of pink bollworms found in: Lint	No. of pink bollworms found in: Seed	Date of picking	Quantity of *kapas* examined in lb.	Period of examination	No. of pink bollworms found in: Lint	No. of pink bollworms found in: Seed
24 Oct. 1934	1	February	...	...	25 Nov. 1934	2½	February	13	...
10 Nov. ,,	1	Do	...	...	11 Dec. ,,	2½	Do	3	1 dead
23 ,, ,,	1	Do	2	...	15 Jan. 1935	2½	Do	21	4
7 Dec. ,,	1	Do	6	4	26 Nov. ,,	23	Do	2	...
18 Jan. 1935	2½	Do	7	5	12 Dec. ,,	23	Do	8	...
22 Nov. ,,	20	December	3	...	20 Jan. 1936	22	Do	10	3
20 Dec. ,,	20	January	11	...					
10 Jan. 1936	20	February	113	7					

It will be seen that cotton of late pickings harbours greater number of pink bollworm than of early pickings and it is in the lint that a large number is found. This is also the case in the Punjab where Bindra [1928] states that the infestation is higher in the middle pickings of *kapas* than in early ones and highest in samples of late pickings.

Examination of seed (sarki)

With a view to determine how the pest behaves in the province with regard to its hibernation in cotton seed, seed of different pickings was examined from time to time. The results are given in Table VII.

TABLE VII

Number of pink bollworm larvae in cotton seed

Picking	Type of seed	Date or period of examination	Quantity of seed in lb.	No. of pink bollworm larvae found in					Remarks
				free state	single seed	double seed	flimsy cocoon	Total	
				1934-35 (Akola)					
I & II . .	V. 434	February	2½	...	...	...	...	...	
III & IV .	Do	Do	2½	...	...	...	...	1	dead
Mixed picking .	Ak. sp. Buri	Do	1	3	...	...	...	3	
				1934-35 (Nagpur)					
Mixed picking .	...	February	1	7	...	...	...	7	brought from market
				1935-36 (Akola)					
Nov. I & II mixed	V. 434	17 Dec. 1935	5	16	...	...	...	16	low grade
Do . .	Do	30 Dec. 1935	5	2	...	...	...	2	ungraded
Nov. & Dec. mixed	Buri	5 Feb. 1936	10	8	1	...	3	12	
Mixed . .	Roseum	17 Feb. 1936	10	1	1	...	...	2	
Do .	Bazar seed	17 Feb. 1936	20	4	...	...	...	4	only one larva healthy
Do . .	Cambodia	25 May 1936	15	1	...	...	...	1	not able to pupate
Do . .	Bazar .	20 May 1936	20	...	...	...	...	...	
Do . .	Buri .	26 May 1936	20	...	...	...	...	...	

It will be seen from the above table that the number of pink bollworm larvae in seed is very small. Those found during December to February either emerge as moths or die due to heat during succeeding months. This leads to the conclusion that in the Central Provinces and Berar, the seed is not the main source of infection of the crop of the next season.

Examination of stored cotton stalks

After *kapas* is gathered some imperfectly developed bolls and damaged locks are left on the plants in the field. Pink bollworm larvae present in them

are thus carried to the place where cotton stalks are stored for fuel or for thatching purposes. These stalks were examined for the larvae. The results show that the cotton stalks harbour long-cycle larvae to a small extent and serve to carry infestation to some degree to the next season (Table VIII).

TABLE VIII

Number of pink bollworm in dry cotton stalks

Date of examination	Quantity in lb. of stalks examined	Quantity in lb. of *kapas* gathered	No. of pink bollworm larvae found	Remarks
		Nagpur		
28 Mar. 1935 .	160	½	*Nil*	Stalks were stored for this purpose both at Nagpur and Akola farms
28 Apr. ,, .	Do	½	2	
28 May ,, .	Do	½	*Nil*	
28 June ,, .	Do	½	*Nil*	
28 Mar. 1936 .	Do	*Nil*	2	
21 Apr. ,, .	Do	*Nil*	1	
26 May ,, .	Do	*Nil*	*Nil*	
		Akola		
28 Mar. 1935 .	160	6	3	
28 Apr. , .	Do	5	4	
28 May ,, .	Do	3	1	
28 June ,, .	Do	3¼	4	
13 Apr. 1936 .	Do	9 oz.	4	Stalks were stored by a cultivator on the 5th mile of Akola-Basim Road
20 May ,, .	Do	1½	1	Stalks were stored on the Government Farm
6 June ,, .	Do	¾	17	Stalks were stored by a cultivator at Hinga village near Government Farm

Examination of volunteer or stray cotton plants

Buds and bolls from stray volunteer cotton plants were collected and examined and the number of bollworms noted. These plants serve as breeding places for pink bollworm during the months June and July as the moths emerging from cotton fields in these months find food plants readily available for oviposition (Table IX).

TABLE IX

Number of bollworms in stray volunteer cotton plants

Locality	Date of examination	No. of plants examined	No. of forms		No. of bollworms		Remarks
			Buds	Bolls	Spotted bollworm	Pink bollworm	
Govt. Farm, Akola .	1 July 1935	121	120	2	5	20	Plants were found in fodder plot
Umri village near Akola	23 June 1936	50	131	10	6	37	Some larvae pupated on 26 June 1936 and emerged as moths on 3 July 1936
	3 July 1936	50	65	7	11	5	Material collected from the same plants as above
	20 July 1936	50	289	6	7	107	All larvae except four were small
Ginning Factory, Akola	12 June 1936	...	46	6	...	...	Plants were near tank
	7 July 1936	...	34	4	...	...	Same plants as above
Nagpur . . .	18-31 Aug. 1936	150	390	326	2	16	Material was collected from ratoon plants kept at Nagpur
	8 Sept. 1936	50	147	322	6	6	Do

Examination of alternative food plants

Though cotton is the most favoured food plant of the pink bollworm, it is sometimes found on *bhindi*, hollyhock and *abutilon*, but their number in them is so small that they can hardly be considered as sources of infestation. Observations carried out during March to August 1935 and March to May 1936 on the alternative host plants of *E. fabia* showed that it is only the tree cotton in which a fairly large number of pink bollworms were found, one or two caterpillars were seen in *A. rosea* and *H. sabdarifa* but these can safely be ignored as means of carry-over. The perennial and volunteer cotton plants are thus the real sources of danger. The following observation gives an idea of the seriousness of this source.

At Chimur, a village in Chanda district, survey was made of the perennial cotton plants in April 1936 and about 100 plants were found growing. From one plant about 7 ft. high and in full bearing, 50 forms were removed and examined. Out of these, 24 were bolls and 26 flower buds. Twenty-two bolls were found attacked by the pink bollworms and from them 22 larvae were collected alive.

Emergence of pink bollworm moths from stored kapas *and seed*

Kapas (unginned cotton) and seed (*sarki*) of different pickings were stored in suitable containers and the number of moths emerged was recorded every week. Not a single moth emerged from $2\frac{1}{2}$ lb. of *kapas* of different pickings kept under observation at Akola from February to September 1935. From 20 lb. of *kapas* similarly kept for the same period during 1936, 13 moths emerged, two from the *kapas* of November picking in the last week of February, three from that of December picking in February and one in April. At Nagpur also during 1935, from 1 lb. of *kapas* of three pickings each, not a single moth was obtained. From 20 lb.of *kapas* in 1936 kept over the same period, four moths were obtained from the *kapas* of November picking about the beginning of May, 10 from the *kapas* of December picking, three in April, five in August and two in September ; and from the January picking, 25 moths emerged, three in April, 20 in August and two in early September.

At Akola, 5 lb. of cotton seed kept from February to September 1935 did not provide a single moth. In 1936, during the same period, 43 lb. of seed were kept under observation and from this lot one moth was obtained from seed of November picking in March, and six from that of December picking, one in February and five in March ; and one from January picking in February.

At Nagpur, 4 lb. of cotton seed were kept in 1935 and 43 lb. in 1936 over the same period, i.e. February to September. Two moths emerged in July 1935 from seed brought from bazar. In 1936, in all 20 moths emerged ; five from seed of the November picking in the month of April, five from that of December picking—three in April and two in August—and ten from the January picking—two in April to May and eight in the first week of August.

The above figures show that *kapas* is not a serious source of reinfection. The only possible danger is from moths which emerge during July and August. The local practice of the cultivators of selling away all *kapas* and not storing it obviates this danger.

There is a negligible number of long-cycle larvae in the seed and the possibility of these developing into adults is greatly minimized when stored in large heaps. Husain, Bindra and others [1931] also support this view when they say that only 1 or 2 per cent of the resting caterpillars reach the moth stage in case of large stores and 6 to 9 per cent in case of small stores.

Feasibility of adopting clean-up measures

Off-season

The period between the close of one cotton season and the beginning of the next is long enough to expose the bollworms to dangers of starvation. The early cleaning of cotton fields involves no extra expenditure and prevents the soil from getting impoverished ; and it also derives maximum benefit from exposure to sun.

Hot weather bhindi

As already pointed out, *bhindi* serves a rich breeding place for almost all pests of cotton which travel on to new cotton crop in the field. Hot weather *bhindi* is grown on a small scale near towns and is not a paying crop as it is

heavily infested with pests and at several places suffers from shortage of water. Even if the crop pays during certain years, to safeguard the larger interests of the cotton growers, its cultivation in summer months should be stopped by all possible measures.

Tree cotton

There is hardly any propriety of growing perennial cotton except as fancy or to have some quantity of lint for preparing wicks for lamps in the daily worship of family gods. There are only stray plants but they are capable of harbouring the pests. By explaining the possible danger from the tree cotton people could be persuaded to remove them.

Other food plants

Some alternative host plants grow in flower or fruit gardens. They are of no economic importance. They are allowed to grow as perhaps it is not realized that they serve as sources of reinfection of cotton pests. If the garden-owners are made aware of the possible harm from these plants, there should be no difficulty in inducing them to keep their gardens free from them.

In short, it does not seem to be very difficult to starve out the bollworms during the non-cotton growing period by adopting the clean-up measures.

SUMMARY

Three types of cotton bollworms, i.e. the pink bollworm (*Platyedra gossypiella* Saund.), the spotted bollworm (*Earias fabia* Stoll.) and the American bollworm (*Heliothis obsoleta* Fabr.) are found to attack cotton in the Central Provinces and Berar.

Spotted bollworm is carried over from one season to another by the alternative food plants such as *H. esculentus*, *H. panduriformis*, *H. sabdarifa*, *Abutilon*, hollyhock, perennial and stray cotton plants.

The status and behaviour of the spotted bollworm is the same as in Gujrat and adoption of clean-up measures is the only way of its control.

Kapas of late pickings harbours a fairly good number of pink bollworm larvae but the practice of selling it away before summer and the severe heat of the season make it difficult for the pest to ' carry-over '.

The pink bollworm larvae do not hibernate in the cotton seed to the extent necessary to carry infection to the next year.

Cotton stalks stored for fuel provide place for some larvae to aestivate and there emerge as moths in June and July but for want of grown-up food plants during these months their activity is retarded.

In the province, as most of the rain is received during July and August, it is very detrimental to the larvae in the soil and moths in the field.

Stray volunteer cotton plants and the tree cotton plants harbour many pink bollworm larvae during June and July but the number of such plants is too small to apprehend any danger of heavy reinfestation. They, however, serve as food for the pink bollworm during the critical period.

Early removal of cotton stalks after the last picking and prevention of volunteer cotton and tree cotton and disposal of all *kapas* before May are the methods to prevent any serious damage by the pink bollworm.

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APPENDIX I

Table A

Average monthly rainfall at Nagpur and Akola

Month	Average of 61 years at Nagpur	Average of 5 years at Akola
April	0·39	0·01
May	0·77	0·52
June	7·88	4·17
July	13·21	8·12
August	11·90	7·30
September	9·56	7·99
October	3·64	2·61
November	0·21	1·26
December	0·59	0·11
January	0·05	0·04
February	0·13	0·29
March	0·11	0·02

Table B

Average monthly humidity at Akola

Month	Year		
	1934	1935	1936
January	57·5	62·2	53·7
February	37·0	49·0	72·7
March	31·0	28·0	42·5
April	28·0	34·0	27·0
May	19·5	20·5	35·5
June	30·5	62·6	77·2
July	83·6	89·0	85·4
August	86·8	85·4	82·0
September	87·5	84·2	85·1
October	62·0	62·8	65·7
November	68·8	55·5	72·6
December	66·1	62·4	69·9

APPENDIX II

TABLE A

Bollworm population in standing crop

Locality	Month and year of examination	No. of plants examined	No. of buds and bolls examined	No. and species of larvae found		
				E. fabia	*P. gossypiella*	*H. obsoleta*
Akola .	September 1935	600	5292	17	0	54
	October ,,	600	5308	142	21	18
	November ,,	600	3746	401	86	0
	December ,,	750	3660	446	153	0
	January 1936	600	3203	185	402	1
	September ,,	100	1448	3	1	1
	October ,,	100	1400	56	10	0
	November ,,	100	398	25	47	0
	December ,,	100	905	27	39	0
	August 1934	*In situ* No. of plants not recorded	3302	6	0	0
Nagpur	September 1934	Do	24804	36	0	2
	October ,,	Do	24676	188	0	22
	November ,,	Do	16393	444	4	1
	December ,,	Do	15505	780	67	0
	September 1935	300	10833	111	0	0
	October ,,	200	3061	28	1	0
	November ,,	400	5569	109	9	0
	December ,,	500	5541	129	53	0
	January 1936	400	5514	95	29	0
	February ,,	200	2514	40	6	0
	August ,,	150	280	0	0	0
	September ,,	600	4286	2	0	2
	October ,,	600	5235	42	8	1
	November ,,	750	3470	131	15	0
	December ,,	600	2078	98	16	0
	January 1937	300	929	17	3	0

TABLE VIII(A)

'Sampling' and 'within samples' variances for each week's observations for number of culms, 1935—40

Week No.	1935		1936		1937		1938		1939		1940	
	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance
1	1·7†	1·1	8·7‡	2·8	1·8	2·8	..	..	4·8	4·0	3·2	2·2
2	4·3‡	2·4	4·3†	2·8	1·8	2·1	..	..	..	..	5·7‡	2·9
3	5·8†	3·7	7·4	6·0	8·2	6·0	8·9	7·2	4·2	4·5	4·8	5·0
4	4·3	5·4	4·5	4·4	7·7	6·3	9·1	8·2	..	..	5·3	4·5
5	38·0‡	5·9	9·0†	6·0	9·8†	6·2	6·7	7·4	7·6	5·8	6·3	4·8
6	9·8‡	5·7	11·4‡	4·8	8·0	9·1	5·3	5·7	2·6	3·6	3·4	4·4
7	6·3	5·9	6·4†	4·3	6·4	7·2	7·5	5·2	4·1	2·9	6·0†	4·1
8	4·7	6·0	4·9	3·4	9·9	7·4	7·8	6·0	5·3‡	3·0	4·6	4·0
9	4·4	4·3	4·6	3·9	6·2	5·7	5·7	4·8	3·2	2·7	3·3	3·7
10	3·8	5·0	4·8	3·6	6·0	6·3	6·2	5·3	3·3	2·7	3·7	3·2
11	4·1	3·5	5·2	3·6	7·3	5·3	5·6	5·2	3·8	3·9	3·2	2·6
12	2·7	3·3	6·5‡	2·9	4·7	5·2	4·4	6·0	2·5	3·0	3·5	3·7
13	5·8‡	3·3	3·1	3·4	4·3	5·3	7·2	5·0	..	..	2·7	3·1
14	2·9	3·6	3·0	3·5	8·4†	5·2	5·6	5·7	..	..	..	..
15	..	..	2·9	3·5	6·0	5·3	..	..	..	..	..	..
16	..	..	..	..	..	..	..	..	..	..	4·0	3·1

† Significant at 5 per cent level

‡ Significant at 1 per cent level

TABLE VIII(B)

'Sampling' and 'within samples' variances for each week's observations for height in cm. and harvest characters, 1935—40

Week No.	1935		1936		1937		1938		1939		1940	
	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance	Sampling variance	Within samples variance
1	4·0	3·8	6·7†	4·4	4·4‡	2·5	..	..	5·4‡	3·0	2·9	4·0
2	4·2	3·5	6·3‡	3·3	5·2‡	2·9	..	..	..	..	6·3‡	3·7
3	4·4†	3·0	3·4	3·2	5·6	4·0	5·3	4·4	5·0†	3·1	7·1	5·7
4	2·6	2·3	5·5	4·2	3·6	2·8	3·2	4·4	..	..	6·5†	3·9
5	11·5‡	4·8	8·9	7·3	3·2	4·2	7·2†	5·3	4·9	8·3	3·5	3·5
6	3·8	4·5	6·3	5·1	4·3	4·3	14·2‡	6·7	10·4	8·9	7·1	6·3
7	2·8	2·2	16·2	11·3	9·0	7·5	11·8	9·3	8·5	7·9	13·5†	8·4
8	15·3‡	8·9	12·0	12·1	23·6	25·1	23·0	17·0	17·6	21·1	7·2	7·2
9	17·5†	10·7	29·5‡	17·1	22·6	18·6	52·0†	33·0	68·3	50·8	36·6‡	21·4
10	31·6†	20·9	20·5	19·5	57·1	41·1	88·0	66·0	40·0	43·3	34·1	25·4
11	36·5	28·4	53·9	69·8	60·3†	40·2	44·0	63·0	47·0	42·0	45·4	43·3
12	45·5†	29·7	71·3‡	36·9	70·0†	43·8	33·0	32·0	39·9	38·7	38·9	38·5
13	41·9	44·2	54·4	58·2	79·7	55·7	53·0	36·0	..	..	30·4	38·1
14	48·5	52·9	83·1†	51·0	62·7†	42·0	41·0	31·0	..	..	..	..
15	..	..	78·7‡	41·4	93·6†	55·7	..	..	..	..	..	..
16	..	..	..	..	..	..	..	..	..	..	64·9	52·0
Panicle length in cm.	..	..	7·2	5·7	5·4	3·3	2·9	2·6	3·3	3·1	2·8	3·0
Straw yield in gm.	4·9	6·9	44·9	32·3	65·0†	13·4	40·7	29·8	16·1	16·8	30·8†	16·7
Paddy yield in gm.	13·3	21·1	33·0	23·0	47·2	40·8	45·0†	28·0	19·0	19·0	39·4†	26·5

† Significant at 5 per cent level ‡ Significant at 1 per cent level

TABLE IX(A)

Analysis of 'within sample' variance into the variance 'between pairs' of bunches and variance 'within pairs' of bunches for a few occasions, 1934

Due to	D. F.	Culms			Height		Paddy yield
		No. of week			No. of week		
		1	9	13	1	13	
Between pairs .	90	1·51	4·14	3·12	7·41	69·40‡	31·54†
Within pairs . .	120	2·00	4·25	3·04	5·61	36·52	20·73

TABLE IX(B)

Analysis of 'within sample' variance into variance 'between pairs' of bunches and variance 'within pairs' of bunches for a few occasions, 1937—40

Due to	D. F.	1937		1938 Paddy yield	1940	
		15th week			9th week	
		Height	Straw yield		Height	Straw yield
Between pairs .	144	70·09‡	49·67†	31·30	25·93‡	16·89‡
Within pairs .	192	44·97	38·21	24·68	17·94	11·30

† Significant at 5 per cent level ‡ Significant at 1 per cent level

SUMMARY AND CONCLUSION

Growth observations on rice were made at the Karjat Rice Breeding Station, Karjat, for the years 1934—40. In 1934 the observations were made on two sets of plots, one of which was planted regularly and the other by the cultivator's method. Observations regarding the number of culms per bunch, height and number of leaves were recorded at intervals of a week for individual bunches, sampling units of eight bunches being chosen at random from the plots. At the time of harvest, the bunches chosen were separately cut and panicle length, straw yield and paddy yield were also recorded for each bunch.

For the regularly planted crop a linear sampling unit of eight bunches was adopted throughout while for the irregular crop in 1934, a square yard sampling structure was adopted where eight bunches along the frame of the square yard were observed.

The results of 1934 observations indicated that there was no material advantage in dividing the plots into sub-plots especially for the crop planted regularly. The regular and irregular crops exhibited significant differences in their features. The number of culms was higher for the irregular crop but the regular crop was the taller of the two during the later stages of growth.

TABLE X(A)

Culms

Sampling, experimental and non-sampling experimental errors and efficiency for all observations, 1934—40

Week No.	1934				1935				1936				1937				1938				1939				1940			
	Sampling	Experimental error	Non-Sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-samplingexperimental error.	Efficiency
1	4·5	4·4	1·9	26	3·0	5·8	5·1	82	6·0	6·9	4·3	50	2·6	4·9	4·4	82	...	...	...	...	3·3	3·7	2·3	48	3·5	5·3	4·2	70
2	3·1	3·9	3·8	56	4·1	8·1	7·2	83	3·7	5·3	4·1	67	2·6	2·9	1·7	46	...	...	...	...	...	...	...	...	3·9	4·7	3·0	52
3	4·7	7·9	9·2	74	4·1	6·4	5·4	73	3·7	6·4	5·5	77	4·3	7·7	6·7	79	5·0	7·8	6·3	73	2·7	6·7	6·3	89	3·2	4·3	3·1	62
4	3·6	5·0	5·2	63	3·1	11·9	11·6	95	3·2	6·3	5·6	83	3·9	7·3	6·4	81	4·4	6·1	4·6	65	...	...	...	...	3·2	2·8	...	13
5	2·7	9·0	12·2	94	7·7	7·1	1·5	22	3·7	5·0	3·7	63	3·7	8·5	7·8	87	3·4	6·8	6·2	84	3·6	5·7	4·6	72	3·4	5·2	4·3	72
6	2·8	6·7	8·7	88	3·3	6·9	6·2	85	4·3	7·2	6·0	76	3·0	8·6	8·2	92	2·9	3·7	2·7	60	2·3	5·0	4·5	85	2·5	4·2	3·5	76
7	3·3	2·2	...	43	2·7	13·0	12·6	97	3·4	8·5	7·9	89	2·8	4·9	4·2	79	3·6	5·4	5·8	70	3·1	5·1	4·3	76	3·4	3·3	1·0	26
8	2·9	6·4	8·2	85	2·5	4·2	3·6	78	3·1	5·4	4·6	77	3·4	8·8	8·2	90	3·5	8·5	7·9	88	3·5	6·3	5·5	80	3·0	5·8	5·8	82
9	3·6	4·7	4·6	58	2·7	4·1	3·3	71	2·9	5·1	4·3	78	2·9	7·2	6·7	89	3·3	9·2	8·7	91	2·7	5·3	4·7	82	2·6	4·0	3·3	72
10	2·7	4·9	5·9	78	2·4	3·5	2·8	68	3·2	4·0	2·8	57	2·8	8·5	8·1	93	3·4	4·5	3·3	62	2·8	2·7	1·0	28	2·9	5·3	4·6	80
11	4·0	2·0	...	...	2·8	3·2	1·9	48	3·2	3·8	2·5	53	3·4	8·1	7·5	88	3·3	5·8	4·9	78	2·9	3·4	2·2	51	2·9	4·7	3·9	75
12	2·6	6·9	9·2	90	2·4	4·4	3·8	81	3·8	3·9	1·9	37	2·7	3·9	3·1	70	2·9	5·2	4·5	79	2·4	3·2	2·4	65	3·1	5·1	4·2	75
13	3·8	4·4	1·2	49	3·2	2·8	...	15	2·5	5·3	4·8	85	2·6	4·0	3·2	72	3·7	3·9	1·9	38	...	...	...	...	2·5	4·1	3·4	75
14	3·2	3·2	3·2	59	2·5	3·7	2·9	70	2·5	4·9	13·9	83	3·7	5·4	4·2	69	3·3	6·5	5·8	83	...	...	...	...	...	...	...	...
15	...	...	...	...	...	...	...	...	2·4	6·3	5·9	90	3·0	5·7	4·9	81	...	...	...	...	...	...	...	...	...	...	...	...
16	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3·2	5·1	4·2	74

TABLE X(B)

Height and harvest characters

Sampling, experimental and non-sampling experimental errors and efficiency for all observations, 1934—40

Week No.	1934				1935				1936				1937				1938				1939				1940			
	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency	Sampling	Experimental error	Non-sampling experimental error	Efficiency
1	4·6	4·5	2·0	26	3·5	4·6	3·3	61	3·3	5·5	4·6	75	3·9	4·8	3·3	57	...	...	...	...	2·9	7·5	7·0	90	2·7	6·3	5·8	88
2	2·3	1·7	...	...	3·0	7·7	7·2	90	2·9	11·3	11·0	96	3·5	5·5	4·5	74	...	...	...	...	...	...	...	...	3·3	4·6	3·5	65
3	3·1	3·9	3·7	56	2·4	5·2	4·7	86	2·0	4·3	3·9	85	3·1	4·8	3·9	72	2·9	5·0	4·2	77	2·2	4·7	4·2	85	2·9	7·4	6·9	89
4	2·0	4·9	6·4	88	1·7	2·6	2·1	70	2·3	9·6	9·4	96	2·0	3·2	2·6	75	1·9	3·4	3·0	81	...	...	...	...	2·4	2·0	...	4
5	1·7	5·9	8·1	100	3·3	3·7	2·2	47	2·7	4·8	4·1	79	1·8	2·7	2·2	71	2·4	6·0	5·6	89	1·8	2·9	2·4	75	1·6	2·0	1·3	55
6	2·7	2·1	...	...	1·7	7·4	7·2	97	2·1	7·3	7·1	95	1·8	4·6	4·3	89	3·1	5·0	4·7	79	2·0	3·3	2·7	74	2·2	2·5	1·5	49
7	2·3	4·9	6·1	84	1·4	3·1	2·8	86	3·1	2·9	0·8	25	2·1	4·0	3·5	81	2·3	4·0	3·5	79	1·7	3·0	2·5	77	2·6	6·5	6·1	89
8	2·6	3·8	4·3	71	2·4	5·1	4·6	86	2·2	5·8	5·4	91	3·5	4·6	3·4	61	2·7	4·3	4·1	79	1·8	4·1	3·8	88	1·7	4·4	4·1	90
9	2·4	6·2	8·2	89	2·1	4·1	3·6	83	2·9	3·0	1·5	39	2·4	3·5	2·3	67	2·9	3·2	1·8	45	2·5	4·5	3·9	79	3·3	8·0	7·4	89
10	2·9	3·8	3·9	59	2·2	4·5	4·1	85	1·9	4·7	4·3	89	2·6	5·2	4·6	83	2·6	6·3	5·8	87	1·5	4·0	3·8	91	2·1	5·2	4·9	89
11	2·3	3·7	4·3	72	1·1	5·1	4·9	93	2·1	9·6	9·5	97	1·7	3·1	2·7	80	1·4	2·3	1·9	75	1·5	2·5	2·1	77	1·6	8·2	8·1	97
12	1·5	2·5	2·9	73	1·3	2·7	2·4	83	1·6	2·1	1·5	59	1·5	2·5	2·1	77	1·1	1·6	1·3	68	1·3	2·7	2·4	84	1·1	5·2	5·1	97
13	1·8	3·8	4·9	84	1·2	2·3	2·1	82	1·3	1·9	1·4	66	1·5	1·8	1·1	51	1·4	2·3	1·9	75	...	...	...	...	1·0	5·0	4·9	97
14	1·2	3·0	3·9	89	1·3	3·1	2·8	88	1·7	1·7	0·9	39	1·3	2·7	2·4	84	1·2	2·1	1·7	77	...	...	...	...	...	...	...	...
15	...	...	...	...	...	...	...	...	1·6	2·3	1·8	67	1·7	2·1	1·4	56	...	...	...	...	...	...	...	...	...	...	...	...
16	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1·4	6·3	6·2	97
Planicle length	1·3	1·2	...	16	...	...	...	...	2·0	4·1	3·7	84	1·9	1·4	...	—16	1·3	1·7	1·1	57	1·5	2·5	2·1	75	1·3	2·5	2·2	82
Straw Yield	3·7	2·7	...	—68	1·0	1·7	1·4	75	3·8	6·4	5·3	76	4·3	6·3	4·9	69	4·0	5·6	4·2	65	2·8	6·8	6·3	89	3·8	7·6	6·7	83
paddy yield	4·7	8·3	10·6	79	2·7	4·0	3·2	70	3·8	3·6	1·0	25	3·9	4·9	3·5	59	4·4	7·7	6·6	78	3·1	7·6	7·1	89	5·2	6·7	5·4	65

TABLE XI

Estimated and actual yields of Paddy for various plots during 1934—40

Plot No.	1934		1935		1936		1937		1938		1939		1940	
	Actual lb.	Estimated lb.	Actual lb.	Estimated lb.	Actual lb.	Estimated lb.	Actual lb.	Estimated lb.	Actual lb.	Estimated lb.	Actual lb.	Estimated lb.	Actual lb.	Estimated lb.
1	18 ·68	17 ·87	..	..	8 ·99	9 ·51	11 ·90	12 ·37	9 ·55	9 ·44	10 ·44	10 ·43	9 ·65	8 ·84
2	16 ·97	17 ·56	..	..	8 ·99	9 ·86	12 ·81	12 ·84	10 ·01	10 ·16	10 ·44	10 ·55	9 ·01	8 ·78
3	16 ·30	16 ·47	..	..	8 ·98	10 ·04	12 ·83	12 ·62	10 ·67	11 ·05	10 ·14	9 ·98	8 ·91	8 ·95
4	15 ·27	15 ·09	..	..	9 ·12	9 ·89	12 ·68	11 ·92	10 ·78	11 ·86	10 ·47	9 ·67	9 ·43	9 ·66
5	14 ·71	14 ·72	..	..	8 ·92	10 ·10	12 ·46	12 ·29	10 ·73	11 ·15	9 ·77	9 ·76	8 ·65	8 ·51
6	..	..	..	..	9 ·07	10 ·00	12 ·32	12 ·37	9 ·50	8 ·96	9 ·48	9 ·37	8 ·84	8 ·68
7	..	..	Not available		9 ·43	10 ·46	11 ·83	11 ·39	9 ·62	9 ·85	9 ·36	9 ·31	9 ·14	9 ·12
8	..	..	..	..	9 ·13	10 ·08	12 ·71	11 ·91	10 ·35	10 ·12	8 ·90	8 ·86	8 ·69	8 ·77
9	..	..	..	..	9 ·22	10 ·07	12 ·60	12 ·07	10 ·22	10 ·02	9 ·17	9 ·11	9 ·19	9 ·07
10	..	..	..	..	8 ·94	9 ·59	12 ·55	13 ·22	10 ·29	10 ·43	9 ·15	9 ·35	8 ·75	9 ·06
11	..	..	..	..	9 ·44	10 ·03	12 ·59	11 ·38	10 ·13	10 ·93	8 ·97	8 ·98	8 ·42	8 ·64
12	..	..	..	..	8 ·87	9 ·09	10 ·95	11 ·32	9 ·67	10 ·31	8 ·08	7 ·91	7 ·49	7 ·16
Total	81 ·93	81 ·71	111 ·0	110 ·9	109 ·10	118 ·72	148 ·23	145 ·70	121 ·52	124 ·18	114 ·37	113 ·27	106 ·17	105 ·24
Plot error per cent	..	..	..	..	2 ·1	..	4 ·4	..	4 ·6	3 ·3	7 ·8	3 ·3	6 ·2	2 ·9

The panicle length at harvest of the irregular crop was shorter. There was no significant difference between the two crops in paddy yield; the irregular crop, however, gave a greater straw yield. Bunches within the same sample showed a positive correlation indicating the need for modifying the structure of the sampling unit.

The sampling was, however, found to be fairly efficient, as indicated by the percentage information obtained on each occasion. It is thus hoped that with a revised structure of the sampling unit, the same percentage for sampling may prove sufficient for sampling the crop.

Lastly, the actual yields of plots have been compared with yields as estimated by sampling and the two were found to agree within three per cent except for the year 1936.

As regards the modification in the linear sampling unit it is suggested that in future years the following structure may be tried.

First row . . $\circ\ \underset{\text{Omit}}{\underline{\times\ \times\ \times}}\ \circ\ \underset{\text{Omit}}{\underline{\times\ \times\ \times}}\ \circ\ \underset{\text{Omit}}{\underline{\times\ \times}}$

Second row . . $\underset{\text{Omit}}{\underline{\times\ \times}}\ \circ\ \underset{\text{Omit}}{\underline{\times\ \times\ \times}}\ \circ\ \underset{\text{Omit}}{\underline{\times\ \times\ \times}}\ \circ$

Each sample will consist of six bunches and four such sampling units may be taken from each plot to keep the percentage sampled the same as hitherto.

In concluding the authors desire to express their gratefulness to Dr L. A. Ramdas, Agricultural Meteorologist, for giving all the facilities required for such a cooperative effort of which the paper is the result. The keen interest which he showed at every stage of the investigation and analyses of the data afforded many opportunities to the authors to discuss the results with him and benefit by his suggestions and guidance. The authors also wish to record their thanks to the staff of the Rice Breeding Station at Karjat for recording the observations.

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A NEW IMPORTANT PEST OF WHEAT CROP IN INDIA

BY

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(With one text-figure)

WHEAT crop in India has been rather free from any serious insect pest except sometime for the attack of termites in the seedling stage. The Pentatomid bug, *Eurygaster maura* Linn. (Fig. 1) and the allied species *E. integriceps* Put., *E. hottentota* F. and *E. austriaca* Schr. are known to be serious pests of wheat crop and other cereals in the Middle East—Syria, Iraq, Persia, Transcaspia, etc. and in central Europe and southern Russia [Sorauer, 1932]. The pest, however, is more widely distributed and is of some importance in almost whole of the European continent, North Africa, Caucasus, Siberia, Japan, China, East Indies, Canada, etc. [Oshanin, 1904]. During his recent visit to Tehran, the writer learnt from the Plant Protection Officer of Persia that *Eurygaster* was one of their most serious pests. It is probable that *Eurygaster* also occurs in Afghanistan.

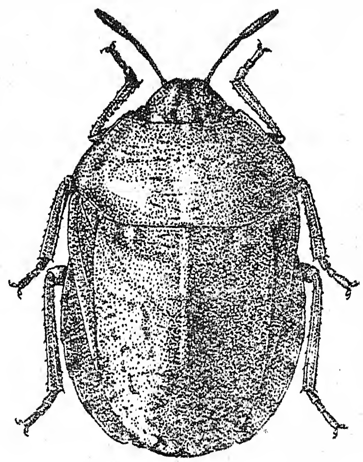

FIG. 1. *Eurygaster maura* Linn. ($\times 4\frac{1}{2}$)

In India, the Imperial Pusa Collection contains specimens collected in 1919 and 1920. The first report of *E. maura* doing damage to wheat was, however, received in April 1926, when one Mr R. K. Nariman, M.I.C.E., F.R.G.S., Rasul P. O., Kulu, sent some specimens of this pest to the Imperial Entomologist for identification and advice. No further report of damage was received though the Imperial Pusa Collection contains some specimens collected from wheat ears at Fort Sandeman in June 1937, and at Kulu in June 1939. In June 1940, the Agricultural Officer, Baluchistan, sent for identification some specimens of *E. maura* to the Imperial Entomologist with the report that a large number of them had appeared in certain parts of the Zhob Valley and " were considered to have caused great damage to the irrigated wheat crop, causing the plants to dry up completely. " The pest was again in evidence in that area during May 1941 and at the same time in 1942,as is reported in the monthly diaries of the Director of Agriculture, Baluchistan. The Imperial Economic Botanist also sent some specimens to the Imperial Entomologist collected by his assistant from wheat and barley plants while on tour in Baluchistan in April 1941. Thus,

there is no doubt that the pest is fully established in Baluchistan though fortunately yet in a limited area, viz. Zhob district.

On account of the proximity of North-West Frontier Province to Zhob district and the fact that its climate is somewhat similar to that of Baluchistan and the Middle East countries, the writer seriously suspects that the pest also occurs in that Province.

Very little is yet known of the biology, life and seasonal history of the pest in India, but a great deal of information has been gathered in other countries which is summarized below.

This pest is known in the Palaearctic region since long time and has occurred in epidemic form in several countries during the last 20 years. Serious damage to wheat crop as a result of outbreak of this pest was reported from Hungary in 1931 [Manninger and Manninger Jr., 1934]; from the province of Verona in Italy [Malenotti, 1933]; and from northern Caucasus [Arkhangelskii, 1941]. The adult bugs are known to migrate from mountainous regions where they pass the late summer and winter to infest wheat fields in the plains in April when atmospheric temperature is 18°-24°C. This migration sometimes takes place in very large numbers, almost forming swarms. The bugs actively suck the juices of wheat plants throughout the day, passing the night under dry leaves or in other hiding places. As a result of their attack, the plants become stunted in growth and eventually wilt. Copulation takes place in 4-6 weeks after the appearance of the adults in the plains. The females lay their eggs generally on the lower part of the young wheat plants early in spring. A single female lays up to 180 eggs in batches of about a dozen each. The eggs are at first green in colour, but later on turn black. The incubation period of the egg is 10-14 days. The newly hatched nymphs suck in the beginning on the upper part of the young shoots, later on the infestation from thence spreads to the ears when the grains are in 'milky' stage, causing them to turn white. The infestation spreads from one field to another, and continues up to harvest time, by which time the bugs are also fully grown. It is stated that as a result of feeding by the bugs, apart from the effect of desapping, the affected shoots and the young ears are killed owing to the introduction of a proteolytic enzyme into the tissues resulting in the arrestation of the formation of seed [Manninger and Manninger Jr., 1933]. Thus, the quality of gluten in the affected wheat grain is very much depreciated and the flour obtained from it becomes unsuitable for baking purposes [Manninger and Manninger Jr., 1933; Schulze, 1936; and Arkhangelskii, 1941]. This happens even if about 5 per cent of the grains are punctured. After the wheat crop is harvested, the adults go back to their winter-quarters in the hills where they hibernate under fallen leaves in forests, dense growth of vegetation, protective strips of trees, or under lumps of soil up to a depth of 50 cm. With the rise of temperature in spring, the bugs once again become active and fly about in swarms towards the plains to infest the wheat crop as described above. Besides wheat, the hosts of the pest are a variety of other cereals, e.g., oats, maize, barley, several grasses (Gramineae), weeds of the families Cyperaceae, Umbelliferae, Compositae, etc. [Schulze, 1936], and sunn-hemp (*Crotalaria juncea*) in Mesopotamia [Silvestri, 1934].

Important natural enemies of this bug include Scelionid egg-parasites of the genus *Telenomus* which are considered to be very efficient in as much

as they can parasitize up to 96 per cent of the host-eggs, two genera of Tachinids, viz. *Phasia* and *Clytiomyia* and an Asilid [Dobrovolski, 1913 ; Malenotti, 1933 ; Tischler, 1938]. It is also interesting to note that Chappellier [1923] found a large number of nymphs of this bug in the body of the nestlings of the common rook.

The control of this pest on a field scale has been attempted in several countries. In most cases effort is made to kill the pest by strong sprays or actually burning the rubbish in the hills harbouring the pest during winter. The places where the pest hibernates or aestivates are sought with a view to effectively killing it. In the plains, the compulsory collection (by law) of these bugs in receptacles containing a contact poison has been reported to be useful. The other methods of control [Arkhangelskii, 1941] recommended are (*i*) ploughing the stubbles in harvested fields up to a depth of 8 in., followed by harrowing; (*ii*) spraying the affected plants with 5 per cent solution of barium chloride ; (*iii*) growing grasses as trap-crops and spraying them with pyrethrum ; and (*iv*) artificial breeding and liberation of the egg-parasites, *Telenomus* spp.

It need hardly be emphasized that it is very essential that the pest should be carefully studied in Baluchistan throughout the year to determine its seasonal-history and alternate food-plants. Then it would be possible to devise suitable measures for its control as well as against its spread to other areas. The pest should also be looked for in the North-West Frontier Province, and the Punjab (Kulu and other hilly and sub-mountainous areas) ; and careful vigilance should be exercised over its increase in numbers. In view of its seasonal and life-history in other countries, its migratory habits and the variety of its alternate food-plants, the writer fears that it will be very difficult to control the pest if it once gets established in India.

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TABLE B

Bollworm population in shed forms

Locality	Month and year of examination	Total No. of plants examined	Total number of shed buds and bolls examined	Number and species of larvae found		
				E. fabia	*P. gossypiella*	*H. obsoleta*
Akola	April 1935	350	1487	85	3	0
	May ,,	350	725	14	0	0
	June ,,	350	24	0	0	0
	September ,,	500	1062	17	0	50
	October ,,	500	2134	121	3	38
	November ,,	500	1016	216	3	0
	December ,,	500	429	80	3	0
	January 1936	500	369	38	27	0
Nagpur	September 1935	300	465	29	1	1
	October ,,	300	2417	25	0	2
	November ,,	300	1242	33	0	0

DIFFERENTIATION OF HYDROGEN CLAYS AND HYDROGEN BENTONITES AND IDENTIFICATION OF MINERAL CONSTITUENTS CONTAINED IN THEM BY ELECTRO-CHEMICAL METHODS

II. MONTMORILLONITIC CLAYS AND BENTONITES*

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(With five text-figures)

IN the previous part [Mukherjee, Mitra, Bagchi and Mitra, 1942] the electro-chemical features of kaolinite and some kaolinitic hydrogen clays have been discussed. This part deals with one hydrogen clay and two hydrogen bentonites prepared from entire clay fractions which gave dehydration curves similar to that of montmorillonitic clay minerals. Results obtained with six sub-fractions isolated from one of the entire hydrogen bentonite fractions have also been presented. Particulars regarding the hydrogen clay and the hydrogen bentonites have been given in Table I. Investigations on the viscous and related properties of bentonites are being carried out in this laboratory under a scheme of research financed by the Assam Oil Company and some results have been published el ewhere [Mukherjee and Sen Gupta, 1940 ; Mukherjee, Sen Gupta and Reid, 1940]. The present investigation is mainly concerned with the electro-chemical properties of these systems and the importance of the electro-chemical data in differentiating hydrogen clays and hydrogen bentonites and also in identifying their principal mineral constituents.

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*Most of the results given in this paper have been taken from the published Annual Report for 1939-40 on the working of a scheme of Research into the Properties of Colloid Soil Constituents financed by the Imperial Council of Agricultural Research, India, and directed by Professor J. N. Mukherjee

**Senior Assistant Soil Chemist under the above scheme

†Assistant Physical Chemist

TABLE I

Particulars regarding hydrogen clay and hydrogen bentonites used

Description of soil or bentonite from which the hydrogen clay or hydrogen bentonite was isolated	Reference number of corresponding hydrogen clay or hydrogen bentonite	Equivalent spherical diameter in microns
Non-lateritic calcareous soil (B-type) from Government farm at Padegaon (Lab. No. 46)	Padegaon-B . .	<2·0*
White bentonite from Bhadres (Lab. No. B. O. C. 3)	Bhadres-B . .	<2·0*
Grey white bentonite from Hati-ki-Dhani (Lab. No. B. O. C. 1)	Hati-ki-Dhani-B .	<2·0*
Do.	Do. B_1 .	0·5 to 1·0
Do.	Do. B_2 .	0·25 to 0·5
Do.	Do. B_3 .	0·10 to 0·25
Do.	Do. B_4 .	0·05 to 0·10
Do.	Do. B_5 .	0·025 to 0·05
Do.	Do. B_6 .	0·025

*Entire clay fractions

EXPERIMENTAL

The methods of preparation of the hydrogen clays and hydrogen bentonites, their electrometric titration with bases and fusion analysis have been full described elsewhere [Mitra, 1936, 1940]. For the separation of the six sub-fractions from the entire hydrogen bentonite fraction Hati-ki-Dhani-B, Ayres' method as described by Whitt and Baver [1937] was followed. The dehydration curves were obtained by the method of Kelley *et al.* [1936].

RESULTS

(a) Properties of entire hydrogen clay and hydrogen bentonite fractions

The results of fusion analysis and the base exchange capacities (per 100 gm.) calculated from titration curves in the presence and absence of salts have been given in Tables II and III. The titration curves are shown in Figs. 1, 2 and 3 and the dehydration curves in Fig. 4.

Unlike the dehydration curves which have more or less the same form and resemble those of montmorillonitic clay minerals [Kelley, *et al.* 1936], the titration curves show very dissimilar features. These are summarized in Table III-A.*

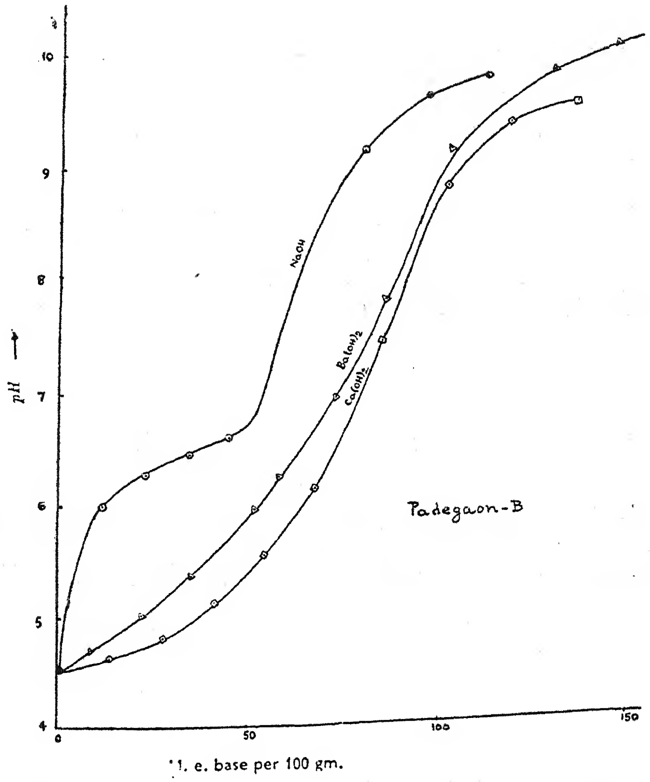

Fig. 1. Potentiometric titration curves of Padegaon-B with different bases

TABLE II

Chemical compositions of entire hydrogen clay and hydrogen bentonites on the ignited base

Reference number of hydrogen clay or hydrogen bentonite	SiO_2 (per cent)	Al_2O_3 (per cent)	Fe_2O_3 (per cent)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
Padegaon-B . . .	56·4	26·7	16·9	3·58	2·51
Bhadres-B . . .	60·4	35·0	4·4	2·93	2·70
Hati-ki-Dhani-B . .	59·0	29·0	9·6	3·46	2·86

*For detailed discussions of the features of titration curves of hydrogen clays obtained from various Indian soils, the reader is referred to Mitra [1936, 1940], Mukherjee, Mitra and Mukherjee [1937] and Mukherjee, Mitra, Chatterjee and Mukherjee [1942]

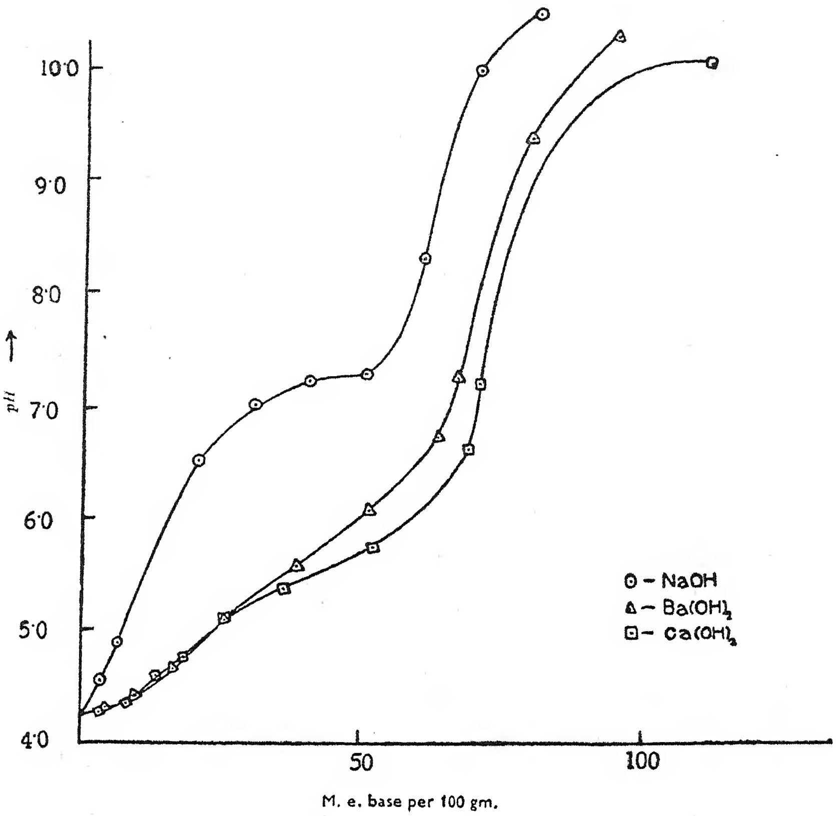

FIG. 2. Potentiometric titration curves with different bases of hydrogen bentonite Hati-ki-Dhani-B

TABLE III

Base exchange capacities of entire hydrogen clay and hydrogen bentonites calculated from titration curves

System	Base exchange capacity in m. e. base for 100 gm. oven dried colloid using					
	NaOH		$Ba(OH)_2$		$Ca(OH)_2$	
	At inflexion point	At pH 7·0	At inflexion pH point	At pH 7·0	At inflexion point	At pH 7·0
Padegaon-B . .	57·0(7·4)*	53·5	89·0(8·05)	74·0	94·0(8·1)	82·0
Bhadres-B . . .	52·5(8·1)	27·5	71·0(7·4)	67·5	72·0(6·85)	72·5
Hati-ki-Dhani-B . .	62·5(8·8)	30·0	66·2(7·3)	64·8	70·2(7·2)	69·2
Hati-ki-Dhani-B+0·1N NaCl	74·5(6·8)	76·0	..	..	..	..
Hati-ki-Dhani-B+0·1N $BaCl_2$	..	..	89·0(7·0)	89·0	..	..
Hati-ki-Dhani-B+0·1N $CaCl_2$	..	..	..	..	82·5(7·0)	82·5

*The figures in brackets denote the pH at the inflexion point; the base exchange capacities of the Hati-ki-Dhani-B series at the second inflexion point have been given.

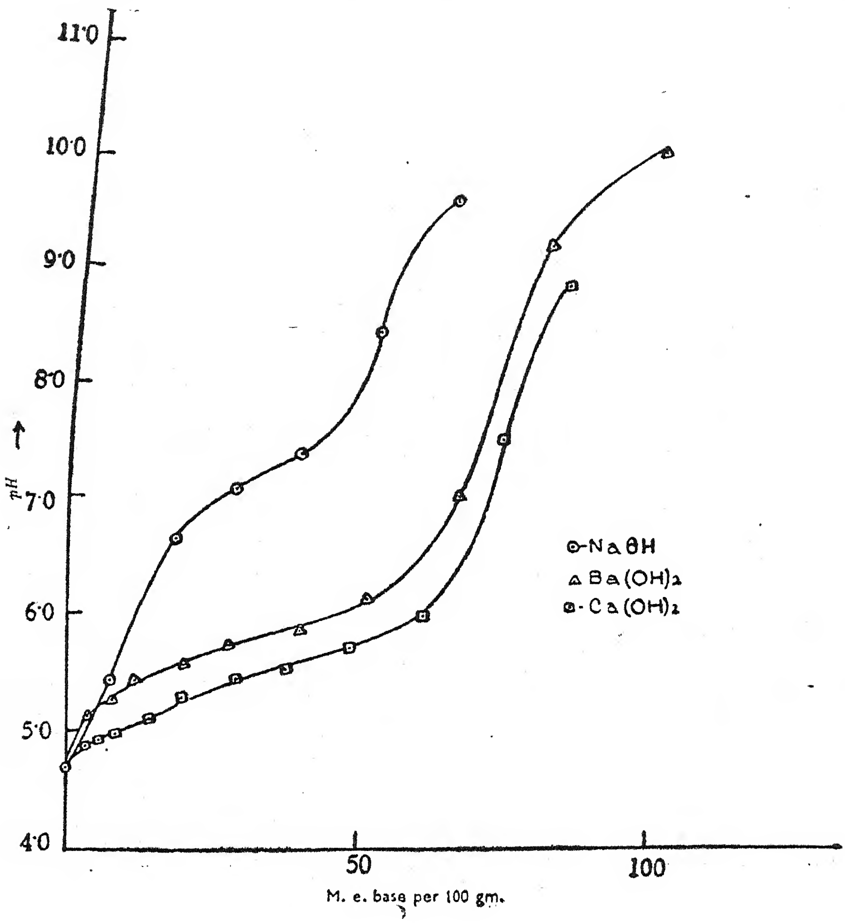

FIG. 3. Potentiometric titration curves with different bases of hydrogen bentonite Bhadres-B

TABLE III-A

System	Nature of titration curve with		
	NaOH	$Ba(OH)_2$	$Ca(OH)_2$
Padegaon-B .	Weak, monobasic	Strong, monobasic .	Strong, monobasic
Bhadres-B . . .	Weak, monobasic	Weak, monobasic	Weak, monobasic
Hati-ki-Dhani-B .	Moderately strong, dibasic	Moderately strong, dibasic	Moderately strong dibasic

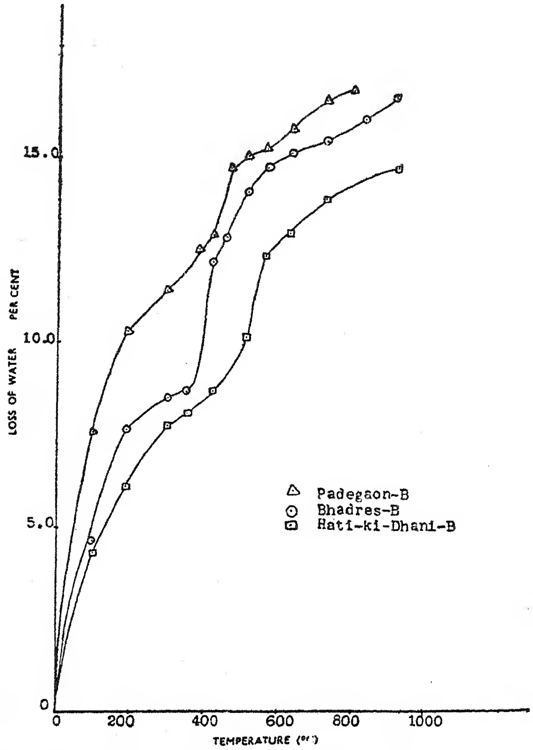

FIG. 4. Dehydration curves of hydrogen clay and hydrogen bentonites

Interesting correlations between the nature of the titration curves and some viscous properties of hydrogen bentonites have been observed by Mukherjee, Sen Gupta and Reid [1940]. According to them, dibasic bentonites such as Hati-ki-Dhani-B are more suitable as drilling muds than the monobasic ones, e.g. Bhadres-B.

The base exchange capacities, calculated from the titration curves, have comparatively high values (Table III) as is to be expected in the case of montmorillonitic clays.

The data recorded in Table II show that Padegaon-B, Hati-ki-Dhani-B and Bhadres-B have markedly different chemical compositions. The percentages of Al_2O_3 and Fe_2O_3 in the two hydrogen bentonites are materially different. Their SiO_2/R_2O_3 ratios and the SiO_2/Al_2O_3 ratio of Bhadres-B approximate those of beidellite rather than montmorillonite. A part of the Al of the gibbsite layer may have been replaced by Fe, especially in Hati-ki-Dhani-B. It would explain the slightly higher value of the SiO_2/Al_2O_3 ratio of Hati-ki-Dhani-B compared with that of beidellite. Presence of iron oxide is possible particularly in the hydrogen clay Padegaon-B which has a comparatively large percentage of Fe, and would account for the observation that both the SiO_2/Al_2O_3 and SiO_2/R_2O_3 ratios of this hydrogen clay differ materially from the corresponding ratios calculated for either montmorillonite or beidellite. These explanations, however, must be accepted with reservation in view of the heterogeneous character of the entire clay fraction and the possibility of its containing more than one clay mineral. The various sub-fractions of the

entire clay may not necessarily contain one and the same clay mineral (see next section ; also, Mitra [1942]) and in such cases the average results of fusion analysis and dehydration studies obtained with the ensemble (i.e. the entire clay fraction) are of little value for the differentiation and identification of its various mineral constituents.

Apart from the differences mentioned above the two hydrogen bentonites reveal the following common features also observed by us with hydrogen clays [Mitra, 1936, 1940 ; Mitra, Mukherjee (S) and Bagchi, 1940 ; Mukherjee (J. N.), Mitra and Mukherjee (S), 1937].

(*i*) The base exchange capacity depends on pH and cation effects. The pH effect is brought out by the fact that the greater the pH the greater is the base exchange capacity calculated from the titration curves. The cation effect is illustrated by (*a*) the dependence on the cation of the base of the base exchange capacity calculated at the inflexion point of the titration curves and more strikingly at a fixed pH, e.g. pH 7·0 and (*b*) by the much higher base exchange capacity obtained on titration in the presence of a large concentration of a neutral salt than in its absence (Table III). In the absence of salts the base exchange capacity decreases in order $Ca(OH)_2 > Ba(OH)_2 > NaOH$ which, however, the changes to $Ba(OH)_2 > Ca(OH)_2 > NaOH$ in the presence of a fixed concentration of the corresponding salts. In the presence of salts the cation effect $Ba^{++} > Ca^{++} > Na^{+}$ is regular in the sense that it follows the lyotrope series and is determined by the order of electrical adsorption of the cations [Mukherjee, 1922] together with their hydration envelopes. In the absence of salts the cations are probably adsorbed in a dehydrated condition which accounts for the irregular or specific cation effect, irregular in the sense that it does not follow the lyotrope series, operating under these conditions.

(*ii*) The titration curves with NaOH, $Ba(OH)_2$ and $Ca(OH)_2$ of any one of the two hydrogen bentonites though showing the same broad features are not mutually superimposable but have very different slopes at one and the same pH. The buffer capacity (at a given pH) which is the reciprocal of this slope follows the order $Ca(OH)_2 > Ba(OH)_2 > NaOH$, in agreement with the irregular cation effect.

(*iii*) The ratio of the free acid (i.e. the H^+ ion concentration*) to the total neutralizable acid calculated at the inflexion point is, with both hydrogen bentonites, of the order of 10^{-2}. This in the classical sense means that the acids are very weakly dissociated. The titration curves of Bhadres-B present features which are in harmony with this conclusion. Those of Hati-ki-Dhani-B, however, instead of showing a weak acid character have the appearance of the titration curve of a moderately strong dibasic acid.

(*b*) *Properties of sub-fractions of hydrogen bentonite*

The chemical compositions and the base exchange capacities (per 100 gm. and per sq. cm. of the average external surface) calculated at the second inflexion point of potentiometric titration curves with NaOH are given in Tables IV and V. Fig. 5 shows the titration curves of four out of the six sub-fractions. The dehydration curves of the sub-fractions have not been separately determined.

*The H^+ ion concentration depends on the amount of the disperse phase in a given volume of the sol. In this work, 2·5 per cent suspensions were used

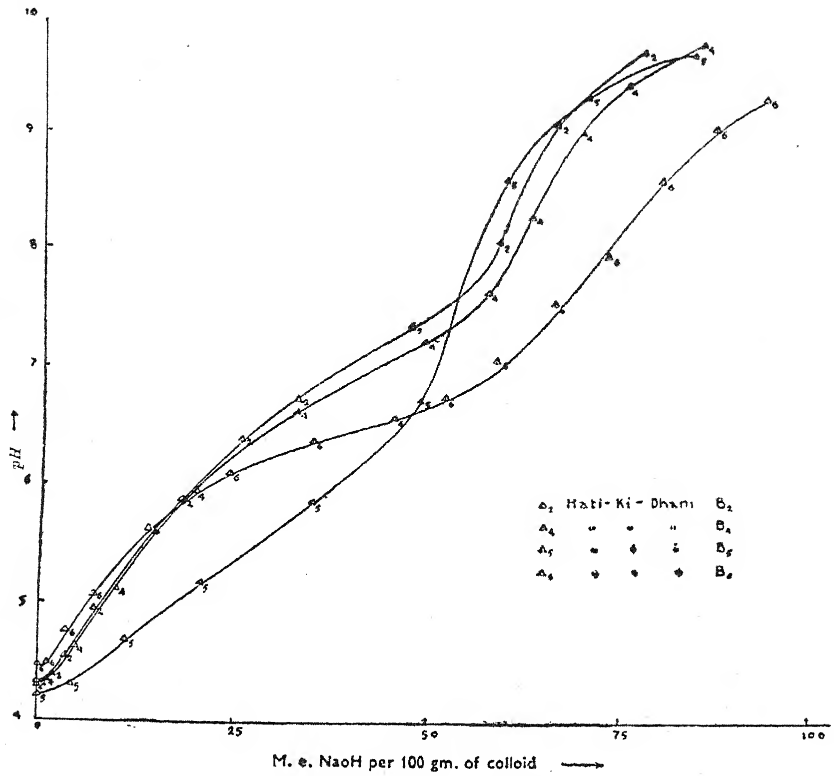

FIG. 5. Potentiometric titration curves with NaOH of sub-fractions of hydrogen bentonite

TABLE IV

Chemical compositions of sub-fractions of hydrogen bentonite

Reference No. of sub-fraction	Reference No. of corresponding hydrogen bentonite	Chemical composition (on the ignited basis)				
		SiO_2 (per cent)	Al_2O_3 (per cent)	Fe_2O_3 (per cent)	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
1	Hati-ki-Dhani-B_1 .	58·8	28·5	11·2	3·51	2·63
2	B_2 .	58·3	22·1	15·4	4·46	3·08
3	B_3 .	58·4	23·9	15·3	4·15	2·95
4	B_4 .	58·4	24·6	14·5	4·04	2·88
5	B_5 .	56·7	31·4	9·3	3·07	2·58
6	B_6 .	60·6	23·0	14·4	4·48	3·21

TABLE V

Base exchange capacities per gm. and per sq. cm. of surface of sub-fractions of hydrogen bentonite

Reference number of sub-fraction	Reference number of hydrogen bentonite	Base exchange capacity at second inflexion point of titration curve with NaOH	
		Per gm.	Per sq. cm. of surface × 10^7
1	Hati-ki-Dhani-B_1 . . .	0·49(8·38)*	166·0
2	B_2 . . .	0·58(8·13)	98·0
3	B_3 . . .	0·59(8·13)	44·5
4	B_4 . . .	0·62(8·10)	21·0
5	B_5 . . .	0·55(8·13)	9·5
6	B_6 . . .	0·75(8·33)	<8·5

The different sub-fractions do not have identical properties. The variations with diminishing particle size may be summed up as follows :—

Chemical composition	Base exchange capacity		Form of titration curves
	Per gm.	Per sq. cm. of surface	
Variations though definite are not regular. They are very marked for fraction one and especially fraction five	Increases except for fraction five	Decreases . .	Similar except for fraction one and especially fraction five

*The figures in brackets denote the pH at the second inflexion point

Judging from the silica-alumina ratios, sub-fractions 2,3, 4 and 6 are likely to contain montmorillonite. Their titration curves have the same form. Fe is perhaps mainly present as free ferric oxide in them. The slightly higher values of the above ratio than 4·0 may be due to the presence of some free silica and/or the replacement of a small fraction of the gibbsitic Al for Fe. The SiO_2/R_2O_3 ratios of these fractions, on the other hand, also admit of the explanation that they are mainly made up of beidellite whose Al has been partially replaced by Fe. The SiO_2/Al_2O_3 ratio of fractions 1 and 5 is nearer to that of beidellite than montmorillonite. The agreement is very close in the case of fraction 5. This considered with the fact that fraction 1 and especially fraction 5 give titration curves which have markedly dissimilar features compared with the other four sub-fractions suggests that the above two fractions are made up of a different mineral, perhaps beidellite. The Fe is mainly present in them as free ferric oxide. Fraction 5, in particular, appears to be made up of beidellite and small quantities of free ferric oxide. Unpublished work of Mr S. N. Bagchi shows that fraction 5 has refractive index and appearance under the microscope quite different from the other fractions.

The differences in the base exchange capacities of the various fractions may be due, at least in part, to their having different specific surfaces. Where the chemical composition does not show material differences as in the case of fractions 2, 3, 4 and 6, the difference in the base exchange capacity may arise from this cause. The finer the fraction the greater will be the base exchange capacity, assuming that the interaction with the base is confined to the outer surface. The results given in Table V, on the other hand, show that the base exchange capacity calculated per sq. cm. of the external surface (Ts) increases with the particle size. A constant value of Ts would be observed if the base exchange capacity were determined by the external surface alone. The variations actually observed show that the reaction with the base is not confined to the outer surface. The particles have considerable inner surfaces and/or fresh layers are progressively exposed as the reaction with the alkali proceeds.

Summary

Two hydrogen bentonites and one hydrogen clay prepared from two Indian bentonites and a calcareous soil from Padegaon (Poona) which give dehydration curves similar to those of montmorillonitic clay minerals have different chemical compositions and their titration curves with bases show markedly dissimilar features. One of the hydrogen bentonites behaves as a weak monobasic acid, and the other as a moderately strong dibasic acid judged from the nature of the titration curves with NaOH, $Ba(OH)_2$ and $Ca(OH)_2$. The NaOH curve reveals a weak monobasic acid character of the hydrogen clay. Its $Ba(OH)_2$ and $Ca(OH)_2$ curves have the appearance of that of a strong monobasic acid.

Four out of six sub-fractions of the dibasic hydrogen bentonite have approximately the same chemical composition and their titration curves have practically the same form. The remaining two sub-fractions, especially one of them, have quite different chemical compositions, and their titration curves present features not observed in those of the other four sub-fractions.

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FRACTIONATION OF SOIL PHOSPHORUS

I. METHOD OF EXTRACTION

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(With three text-figures)

DEAN [1938] in an attempted fractionation of the soil phosphorus showed that by extracting the soil successively with alkali and acid, it was possible to divide the phosphorus compounds of the soil into three broad divisions, viz. (*a*) organic compounds soluble in sodium hydroxide, (*b*) inorganic compounds dissolved by sodium hydroxide followed by an acid, and (*c*) insoluble compounds. The methods of extraction and determination of the fractions adopted by him were more or less empirical in nature. This study was undertaken at the Rothamsted Experimental Station as an extension on Dean's work carried out in the same laboratory. In a method of fractionation which is based on extraction, it is essential that the extraction should be as thorough and complete as possible and that there should not be any transformation of one fraction into the other during extraction and determination. The object of the present work was to make a critical examination of the method employed by Dean with special reference to the conditions of extraction. In an earlier communication by the author [Ghani, 1942] an improved procedure for the determination of organic phosphorus in the alkali-soluble fraction has been described.

Removal of exchangeable bases before alkali extraction

It was repeatedly observed by the earlier workers that alkali-soluble phosphorus increased if the soil was treated with a dilute acid. The effect of the acid upon the soil may be partly to break up soil particles and thus expose more phosphate to the subsequent alkali extraction and partly to remove exchangeable calcium which would otherwise precipitate a part of the phosphorus dissolved by the alkali. Schollenberger [1918, 1920] in his study of the soil organic phosphorus used different acids of varying strength for pretreating the soil before ammonia extraction and found that alkali-soluble phosphorus was the highest with one per cent hydrochloric acid pretreatment. Potter and Benton [1916] used $N/5$ HCl for the purpose. Williams [1937] and Dean [1938] leached the soil with normal ammonium acetate and semi-normal sodium acetate respectively as a preliminary to soda extraction. In many of the neutral and calcareous soils such treatments were found to cause a large increase in the amounts of sodium hydroxide-soluble phosphorus and the effect increased significantly with pH values of soils.

In adopting a procedure where fractionation of the soil phosphorus is aimed at, the pretreating agent should effect complete removal of the exchangeable bases without dissolving phosphorus, organic or inorganic, which would come under other categories. To this purpose the dilute mineral acids do not answer well. Hydrochloric acid, for example, dissolves appreciable amounts of iron phosphates and in some cases organic phosphorus as well. Dilute acetic acid, on the other hand, is known to dissolve only the readily available phosphorus of the soil in addition to the removal of exchangeable bases. Its use, therefore, in a scheme of fractionation serves the double purpose of removing the exchangeable bases and of getting the available phosphorus fraction. On trial it was found that $N/2$ acetic acid dissolved the calcium phosphates almost fully but the phosphates of iron and aluminium were only slightly soluble. Moreover, determinations of organic phosphorus in the acetic acid extracts of about two dozens of organic soils showed that the amount of organic phosphorus dissolved by this reagent was in all cases negligible. A study of the comparative effectiveness of sodium acetate (used by Dean) and acetic acid as pretreating agents also showed that acetic acid pretreatment rendered more phosphorus alkali-soluble than did sodium acetate [Ghani, 1938].

Alkali extraction

Gortner [1916] demonstrated that there might exist wide differences between the solvent action of different alkalies or different concentrations of the same alkali upon the organic matter of the soil. Schollenberger[1918], from a comparison of the solvent action of the hydroxides of alkali metals and ammonia, showed that at the quarter normal concentration the fixed alkalies extracted more total phosphorus than did normal ammonia but about the same amount of organic phosphorus. In all cases the quarter normal solution dissolved more phosphorus than the normal solution. Sodium carbonate extracted less phosphorus than sodium hydroxide and potassium hydroxide. Williams [1937] found that even the weakest concentrations of sodium hydroxide extracted the greater part of the phosphorus from the soil and that with increasing strength of alkali the amount extracted was constant or showed a slight tendency to increase. This was specially true when the exchangeable calcium was removed by ammonium acetate pretreatment. These evidences would indicate that quarter normal alkali can be used effectively for extracting the alkali-soluble phosphorus of the soil. This also reduces the possibility of the hydrolysis of the organic phosphorus compounds by a stronger alkali. The solvent action of sodium carbonate and sodium hydroxide is compared below, the extraction being done by Dean's procedure.

Sodium carbonate and sodium hydroxide extraction

Ten grammes of acetic acid pretreated soil were placed in a beaker containing 100 c.c. of $N/4$ sodium carbonate solution and digested overnight on a water-bath. The beaker was covered with a clock glass to reduce evaporation. The suspension was next washed into a 500 c.c. measuring flask, made to volume and then allowed to stand for 24 hours. Inorganic and organic

phosphorus in the extract were determined on an aliquot of the supernatant liquid by the method of Ghani [1942]. The extraction with sodium hydroxide was done exactly in the same way except that 5 gm. of soil were taken instead of 10 gm. The results for five soils are shown in Table I.

TABLE I

Sodium carbonate and sodium hydroxide soluble phosphorus

(Mg. P_2O_5 per 100 gm. of soil)

Soil	A 1441 Broad balk head land	A 1442 Woburn	A 1443 Bangor	A 3338 Broadbalk wilderness	A 2865 King's Lynn
Inorganic—					
Na_2CO_3	39	27	65	26	20
NaOH	62	41	160	40	40
Organic—					
Na_2CO_3	33	19	50	18	16
NaOH	64	33	160	56	32
Total—					
Na_2CO_3	72	46	115	44	36
NaOH	126	74	320	96	72

It will be seen from the above table that sodium carbonate extracts much less phosphorus than sodium hydroxide. This is true for both the organic and inorganic fractions. The difference was supposed to be due to the different soil-solvent ratios adopted in the two extractions and hence the effect of soil-solvent ratio on the amount of alkali-soluble phosphorus was next investigated.

SOIL-SOLVENT RATIO

Fraps [1911] found that phosphorus extracted by $N/5$ nitric acid and 4 per cent ammonia decreased as the quantity of soil used per 100 c.c. of the solvents increased. Schollenberger [1918] working with 4 per cent ammonia showed that soil-solvent ratio had no appreciable effect on the total amount of phosphorus extracted.

0·5, 1, 2, 5 and 10 gm. of soil were extracted with 100 c.c. of $N/4$ sodium carbonate according to the method already described and phosphorus both organic and inorganic determined in the extracts. The results are shown in Table II.

TABLE II

Soil-solvent ratio in sodium carbonate extraction

(Mg. P_2O_5 per 100 gm. of soil)

Soil-solvent ratio	1/10	1/20	1/50	1/100	1/200
A 1441—Rothamsted					
Inorganic . .	39	52	88	76	66
Organic . .	33	36	37	54	84
Total .	72	88	125	130	150
A 3328—Carbello					
Inorganic . .	30	54	78	82	90
Organic . .	50	56	92	88	88
Total .	80	110	170	170	178
A 3457—Saxmundham					
Inorganic . .	27	37	45	51	42
Organic . .	11	7	20	29	38
Total .	38	44	65	80	80

The results show that the amount of phosphorus extracted increases as the soil-solvent ratio decreases. This observation holds true for the total, organic and inorganic phosphorus in the three soils studied, except that with soils No. 1441 and 3457, the inorganic fraction shows a tendency to decrease if less than 1 gm. of soil is used per 100 c.c. of the solvent. This discrepancy may, in all probability, be due to the sampling error involved in weighing out 0·5 gm. of soil. It will be noticed, however, that the increase in alkali soluble phosphorus is relatively small if the soil-solvent ratio is less than 1 : 100. This may, therefore, be taken as the suitable ratio in alkali extraction of soils.

For comparison, the sodium hydroxide soluble phosphorus of the soils was determined using 1/100 and 1/20 ratios. The results are given in Table III.

TABLE III

Soil-solvent ratio in NaOH extraction

(Mg. P_2O_5 per 100 gm. of soil)

Ratio	1/20	1/100
A 1441—		
Inorganic	62	80
Organic	64	60
Total	126	140
A 3328—		
Inorganic	96	100
Organic	140	150
Total	236	250
A 3457—		
Inorganic	41	55
Organic	19	40
Total	60	95

A comparison of Tables II and III shows that sodium hydroxide-soluble phosphorus, both organic and inorganic, at the same soil-solvent ratios are in all cases greater than the corresponding values obtained with sodium carbonate. This indicates that sodium carbonate does not completely extract the whole of the phosphorus that is supposed to fall in the alkali soluble category.

TEMPERATURE OF EXTRACTION

In the earlier works of Fraps [1911], Potter and Snyder [1918] and Schollenberger [1918] the alkali extraction was done at room temperature by shaking for a period of time arbitrarily chosen. The recent workers, however, resorted to hot extraction. Williams [1937] extracted the soil with boiling sodium hydroxide solution by keeping the mixture in gentle ebullition on a hot plate for $2\frac{1}{2}$ to 3 hours. Dean [1938] digested the soil with alkali at 95°C. overnight. These conditions were all adopted arbitrarily and nothing is known about the effect of temperature and time of extraction upon the amount of phosphorus extracted and on possible hydrolysis of the organic phosphorus compounds during the extraction. The author [Ghani, 1942] has already reported data to show that hydrolysis of organic phosphorus takes place during bromine oxidation of the alkali extract at the boiling temperature.

To test the above points, extraction with sodium hydroxide was done in the following ways :—

1. At room temperature by shaking for different periods of time, viz. 2, 4, 8, 24 and 48 hours.
2. At 40°C. by immersing the mixture in a water-bath kept at 40°C. for different periods of time, viz. 1, 2, 4, 8 and 16 hours.
3. At 95°-100°C. in a water-bath for different periods of time, viz. 4, 8, 16, 32 and 48 hours.

The results are shown in Tables IV, V and VI.

TABLE IV

Alkali extraction at room temperature

(Mg. P_2O_5 per 100 gm. of soil)

	2 hours	4 hours	8 hours	24 hours	48 hours
Inorganic—					
A 1441	45	48	49	51	52
A 3328	64	62	66	75	71
A 3457	31	28	32	39	31
Organic—					
A 1441	57	57	52	69	70
A 3328	136	153	139	115	139
A 3457	24	22	18	16	24
Total—					
A 1441	102	105	102	120	122
A 3328	200	215	205	190	210
A 3457	55	50	50	55	55

TABLE V

Alkali extraction at 40°C.

(Mg. P_2O_5 per 100 gm. of soil)

	1 hour	2 hours	4 hours	8 hours	16 hours
Inorganic—					
A 1441	48	54	56	53	58
A 3328	65	68	70	74	75
A 3457	30	37	37	32	36
Organic—					
A 1441	62	58	59	67	67
A 3328	145	132	130	146	145
A 3457	28	23	25	26	24
Total—					
A 1441	110	112	115	120	125
A 3328	210	200	200	220	220
A 3457	58	60	62	58	60

TABLE VI
Alkali extraction at 95°-100°C.
(Mg. P_2O_5 per 100 gm. of soil)

	4 hours	8 hours	16 hours	32 hours	48 hours
Inorganic—					
A 1441	78	78	79	100	101
A 3328	92	98	100	115	143
A 3457	44	44	52	69	74
Organic—					
A 1441	52	57	66	45	46
A 3328	128	125	145	125	99
A 3457	20	31	40	21	16
Total—					
A 1441	130	135	145	145	147
A 3328	220	222	245	240	242
A 3457	64	75	92	90	90

From Table IV it is seen that the time of shaking at room temperature has practically no effect on the alkali-soluble phosphorus fraction. All the three quantities remain nearly constant, with a slight tendency to increase with time. At 40°C. also (Table V) no significant variation in the results is obtained, both organic and inorganic phosphorus remaining at a fairly constant level irrespective of the duration of extraction. By comparing Tables IV and V, it will further be observed that the fractions extracted at 40°C. are not higher than those obtained at the room temperature, suggesting neither a greater solvent action nor hydrolysis at 40°C. The results of hot extraction presented in Table VI, reveal completely different things. Here the inorganic phosphorus shows a slight tendency to increase to the 16 hours digestion period after which there is a rapid increase. On the other hand, the organic phosphorus at first increases similarly to that period of digestion and then falls down rapidly. This contrasting behaviour of the two fractions can be explained only as follows :— The amount of organic and inorganic and hence the total phosphorus dissolved in the alkali increases with time but hydrolysis of the organic phosphorus takes place at the same time. After about 16 hours, extraction is nearly complete but decomposition proceeds very rapidly thereby reducing the amounts of organic phosphorus in

the extract and increasing the inorganic counterpart. That the total phosphorus did not change after 16 hours shows that extraction was complete by that time. Moreover, a comparison of the 48 hours extraction figures in Tables IV and VI will show that the inorganic phosphorus was almost doubled in all the three soils by raising the temperature of extraction to 100°C. whereas the organic phosphorus was reduced by about one-third its value. This clearly shows that decomposition of organic phosphorus undoubtedly takes place during extraction at a high temperature. The change in inorganic and organic phosphorus is shown graphically in Fig. 1.

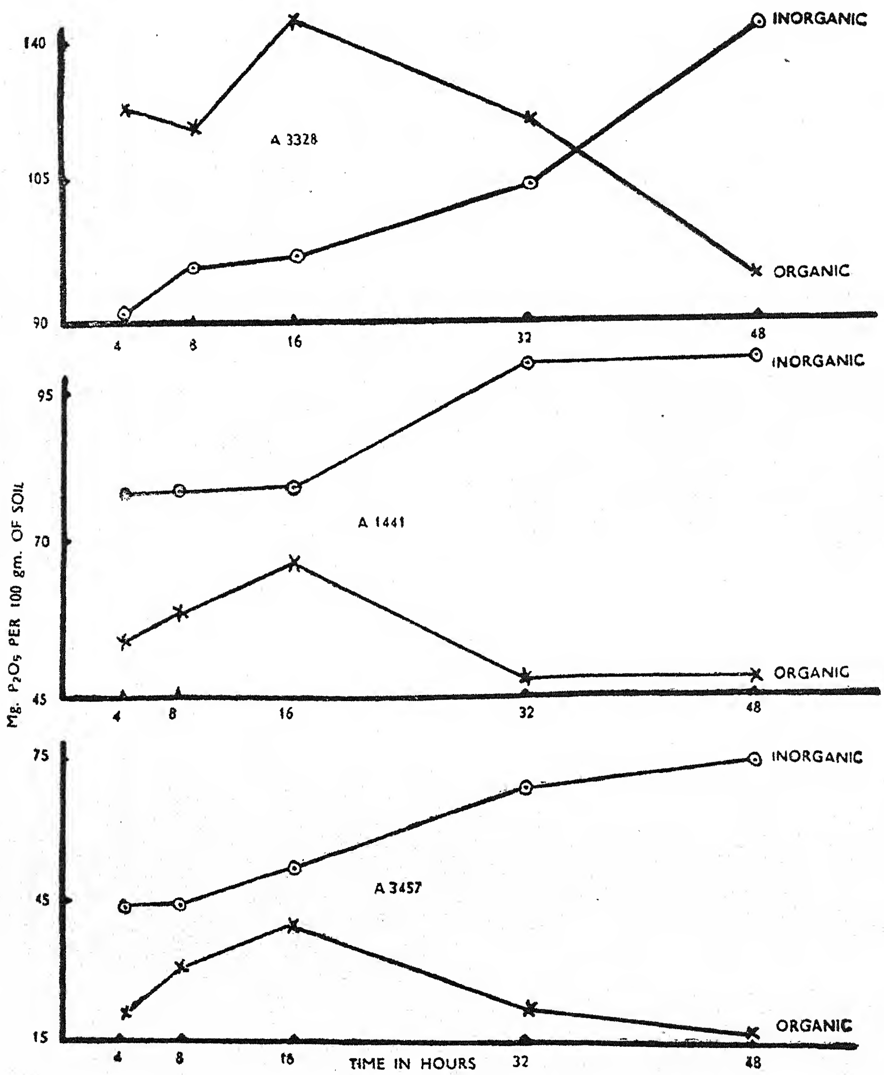

FIG. 1. Showing the change in inorganic and organic phosphorus with time at alkali extraction at 100°C.

From what has been stated above it is evident that hot extraction method is completely unsuitable for the purpose of fractionation of the soil phosphorus as it prevents any true distinction being made between the organic and inorganic phosphorus dissolved by alkali. The alkali extraction should, therefore, be carried out at the room temperature by shaking and extraction should be repeated, if necessary, with the residual soil. It has been shown by various workers that extraction of the soluble constituents is not completed by one treatment and that sometimes five or more treatments are necessary.

Repeated extraction of the soil

In repeated extraction, it is advisable to remove one extract completely before proceeding to the next. This is particularly important when different solvents are to be used in succession. By the ordinary method of filtration an unknown volume of water (and hence an unknown amount of phosphorus) retained by the soil and the filter paper goes over to the next extract, thereby reducing the concentration of the latter and also adding some phosphorus to it. Secondly, in a long series of successive extractions a filter paper will be each time added to the bulk of the soil causing great inconvenience in the filtration which in itself is a tedious process. To overcome these difficulties and inaccuracies and also to ensure complete filtration, a Pasteur-Chamberland candle was used in an apparatus similar to that designed by Dreyspring and Heinz [1935].

The design of the apparatus

The apparatus is shown in Fig. 2. A Pasteur-Chamberland candle (L3

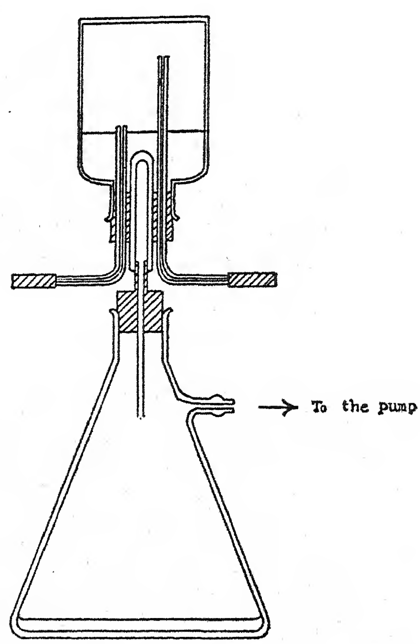

Fig. 2. Filtering apparatus for repeated extraction of the soil

7·5 cm.) is fitted into a rubber bung which fits tightly into a 250 c.c. bottle with the candle inside the bottle. Two heavy-walled capillary glass tubes are also inserted into the stopper, their outer ends being bent at right angles and fitted with rubber tubes so that they can be closed by inserting two small pieces of glass rod. The length of the tubes inside the bottle are adjusted so as to keep their ends above the surface of 100 c.c. of liquid both when the bottle is in an erect and in an inverted position. The bottle is supported in an inverted position by fixing the candle on to a glass tube passing through a bung into a filter flask, the lower end of the tube being below the side tube of the flask so that no filtrate is drawn out by suction.

Procedure for repeated extraction of soil

One gramme of soil and 100 c.c. of the solvent are placed into the bottle which is then closed with the rubber stopper containing the porous candle. Both the capillaries are then closed with pieces of glass rods and the bottle shaken in a mechanical shaker for a period of four hours. After the shaking is over the bottle is fitted in the filter flask in an inverted position and allowed to stand for sometime so that the suspended soil particles may settle

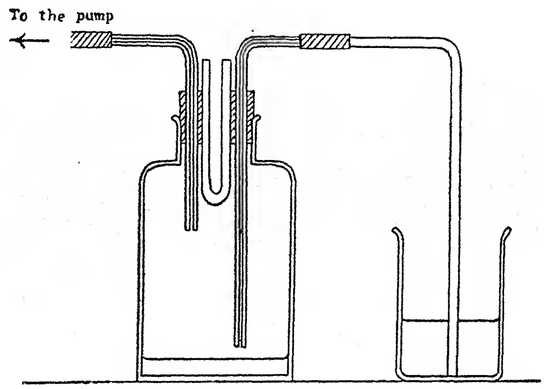

Fig. 3. Apparatus in an erect position while the solvent is being drawn in

down. This prevents the pores of the candle from being clogged by suspended matter during the suction. When the particles have settled down, suction is applied. In the case of highly organic soils filtration of the alkali extract is very slow and is allowed to go on overnight. When the filtration is over, the bottle is disconnected from the filter flask and connected to the pump through one of the capillary tubes, the other one being dipped through a bent tube into a measuring cylinder or beaker containing a known volume of the desired solvent. The solvent is thus drawn into the bottle (Fig. 3). This procedure is used because if the stopper is displaced from the bottle, the soil is disturbed and it becomes difficult to wash all of it quantitatively into the bottle. The extraction is then repeated with the same or any other solvent as desired.

ACID EXTRACTION AFTER ALKALI

After the soil is thus extracted with acetic acid and sodium hydroxide, presumably most of the apatites of the soil are left unaffected in the residue. To remove this fraction, the residual soil from the alkali extraction was in the same way repeatedly extracted with $2N$ sulphuric acid. The phosphorus still left in the soil after these combined acid and alkali extractions would definitely represent an inert combination and may, as suggested by Marshall [1935], be present as an integral part of the clay lattice.

THE PHOSPHORUS FRACTIONS

In the light of the above study, the soil phosphorus may be divided into five groups as described below. The chemical nature of the groups will be fully dealt with in part II of this series.

1. Acetic acid-soluble. Mono-,di- and tri-calcium phosphates. This probably constitutes the fraction that is easily available to plants.
2. Alkali-soluble inorganic. Iron and aluminium phosphates. This probably constitutes the fraction that is definitely available to plants.
3. Alkali-soluble organic. Total organic phosphorus of the soil (nucleic acid, phytin, leoithin, etc.). This is available to plant only through decomposition.
4. Sulphuric acid-soluble. Phosphates of apatite type. This is probably unavailable to plant.
5. Insoluble. Presumably this forms an integral part of the clay complex and is inert so far as phosphate nutrition of the plant is concerned.

THE MODIFIED METHOD OF FRACTIONATION

The procedure of fractionation finally adopted may be described as follows :—

One gramme sample of the soil is introduced into the filtering apparatus (described before) and shaken continuously with 100 c.c. of $N/2$ acetic acid for two hours in a mechanical shaker. The extract is filtered immediately after shaking and acetic acid soluble phosphorus determined on a suitable aliquot of the extract.

The residual soil in the apparatus is then similarly shaken with 100 c.c. of $N/4$ sodium hydroxide and extraction repeated until the phosphorus extracted by alkali is very low or nil. The inorganic and organic phosphorus in the extracts are determined by the method of Ghani [1942]. To get the phosphorus fraction of the soil, the fractions obtained in the several extracts are summed up.

The residual soil is again repeatedly extracted by shaking with 100 c.c. of $2N$ sulphuric acid and phosphorus determined on an aliquot of the extract.

To get the insoluble fraction, the sum of the phosphorus dissolved by acetic acid, sodium hydroxide and sulphuric acid is subtracted from the total soil phosphorus determined separately by the A. O. A. C. gravimetric method.

The outline of the method is presented below diagrammatically.

Soil (1 gm.)
Extracted with 100 c.c. $N/2$ acetic acid by shaking

Extract
$CaH_4(PO_4)_2$
$CaHPO_4$ and $Ca_3(PO_4)_2$

Residue
Repeatedly extracted with 100 c.c. $N/4$ sodium hydroxide by shaking

Extract

Inorganic
($FePO_4$, $AlPO_4$)

Organic
(Nucleic acid, Phytin, Lecithin, etc.)

Residue
Repeatedly extracted with 100 c.c. $2N$ sulphuric acid by shaking

Extract
(apatite)

Residue
(as integral parts of clay complex)

Application of the proposed method of fractionation to eight soils of different types

Eight soils of different types and having different manurial history were selected for analysis according to the procedure developed and described before. Their essential characters are summarized below.

Description of soils

Acid mineral soils

A 1441. A heavy loam from the edge of Broadbalk continuous wheat Rothamsted. Unlike the soils of the old experimental plots, this soil is acid having formed part of an old grass headland which was ploughed up long after the wheat experiments began. This sample was used in A. E. A. Co-operative Experiments on soil analysis.

Neutral mineral soils

A 3457. A calcareous clay loam from calcareous boulder clay at the Sexmundham Experimental Farm, East Suffolk. Crops on this land responded well to phosphate.

A 2328. A heavy loam from Broadbalk continuous wheat plot 2 B, receiving 14 tons of farm-yard manure per acre annually since 1843.

Acid mineral soil ploughed out from long leys :

A 3328. An acid loam from Carbello, Cranberry, Ayrshire, derived from drift. Taken from a Swede plot in which high soluble slag increased the yield from 2 to 25 tons per acre. The land for Swedes was ploughed out after several years in ley.

Organic soils

A 3769. An acid peaty loam from Flatterton, Inverkip, Refrewshire taken from a Swede plot in which basic slag increased the yield from three to 24 tons per acre.

A 3246-7. A heavy acid fen soil from Whittlesea, Peterborough. Taken from 27-plot NPK experiments in which superphosphate gave a significant increase in yield. This soil was chosen because its citric acid soluble P_2O_5 (62 mg. per cent) was greatly in excess of acetic and soluble P_2O_5 (4 mg. per cent).

A 3560-1. A heavy acid fen soil from Littleport Farm, from a 27-plot NPK potato experiment in which superphosphate gave a significant increase in yield.

Results and discussion

The results of fractionation showing the analyses of the individual extracts are shown in Table VII. In Table VIII are given the summarized results obtained by the summation of the repeated extracts with each solvent. For convenience of study the data are expressed both as per cent of the soil and as per cent of the total soil phosphorus.

From the data in Table VII it is seen that both organic and inorganic phosphorus fell off rapidly in successive extracts and that five extractions were necessary to bring down the sodium hydroxide soluble phosphorus to a low quantity. Schollenberger [1918] showed that in successive extracts of soils with 4 per cent ammonia the soluble phosphorus was quite low in the fourth extract, it was about 2·3 mg. P_2O_5 per 100 gm. of soil. It will also be seen that no organic phosphorus was dissolved by the acetic acid and sulphuric acid before and after the alkali extraction respectively.

Table VIII shows the relative proportion of the various phosphorus fractions in the different types of soil under study. The four fractions determined by combined acetic acid, alkali and sulphuric acid extraction account for at least 95 per cent of the total phosphorus in five of the eight soils, and for over 80 per cent in all of the soils. Considering the inevitable errors ir adding up so many analyses, it would appear that almost all of the soil phosphorus is soluble under these conditions of extraction.

The acetic acid soluble fractions were very small in all soils, except those from manurial plots at Woburn, Rothamsted and Saxmundham (A 2242, A 3457 and A 2328). It is noteworthy that the Rothamsted Broadbalk plot which receive farmyard manure annually was outstandingly rich in readily available inorganic phosphorus. On the other hand, the acid organic soils and the grass headland soil from Rothamsted showed deficiency in this form of phosphorus.

TABLE VII

Phosphorus fractions in repeated extracts

(Mg. P_2O_5 per 100 gm. of soil)

—	A 1441		A 2242		A 3457		A 2328		A 3328		A 3769		A 3246-7		A 3560-1	
	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.
N/2 acetic acid	2·3	...	9·8	...	10·6	...	59·2	...	1·6	...	1·3	...	3·4	...	9·2	...
N/4 sodium hydroxide—																
1	49·0	54·0	89·0	34·0	25·5	25·0	87·5	35·0	73·7	124·0	92·0	215·0	247·5	80·0	66·2	54·0
2	7·0	9·5	12·0	3·2	3·6	6·1	10·5	5·0	8·5	11·5	8·2	20·0	28·5	17·0	13·0	17·0
3	2·0	3·2	1·6	1·8	0·4	2·8	3·8	1·7	2·3	2·2	2·3	5·2	11·0	8·7	9·0	5·2
4	2·2	0·9	3·4	2·3	0·3	1·6	3·6	2·5	0·7	1·8	1·7	1·5	11·1	1·3	2·0	5·4
5	2·1	0·9	0·3	0·6	0·5	1·7	1·0	1·0	0	0	0·2	1·8	3·2	0·7	0·2	2·2
Total	62·3	68·5	106·3	41·9	30·3	37·2	106·4	45·2	85·2	139·5	104·4	243·5	301·3	107·7	90·4	83·8
2*N* sulphuric acid																
1	14·0	...	9·6	...	9·7	...	12·6	...	7·8	...	29·6	...	43·2	...	28·0	...
2	4·4	...	5·2	...	6·2	...	6·8	...	5·1	...	8·0	...	16·0	...	10·2	...
Total	18·4	...	14·8	...	15·9	...	19·4	...	12·9	...	37·6	...	59·2	...	38·2	...

TABLE VIII

Fractions of soil phosphorus

(Mg. P_2O_5 per 100 gm. of soil)

——	Acetic acid soluble	Inorg. alkali soluble	Org.	H_2SO_4 soluble	Insoluble (by difference)	Total
Acid mineral—						
A 1441 Roth.	2	62	68	19	19	170
A 2242 Wob.	10	106	42	15	41	214
Neutral mineral						
A 3457 Sax.	11	30	37	16	5	99
A 2328 Broad.	59	106	45	19	39	268
Acid mineral ploughed after long ley—						
A 3328 Carb.	2	85	140	13	—7	233
Peaty soil—						
A 3769 Flat.	1	104	243	38	—7	379
A 3246-7 Pet.	3	301	108	59	—5	466
A 3560-1 Lit.	9	90	84	38	14	235
		Fractions as percentage of total P_2O_5				
A 1441 .	1	36	40	11	11	..
A 2242 .	5	50	20	7	19	..
A 3457 .	11	30	37	16	5	..
A 2328 .	22	40	17	7	15	..
A 3328 .	1	36	60	6	—3	..
A 3769 .	0	27	64	10	—2	..
A 3246-7 .	1	65	23	13	—1	..
A 3560-1 .	4	38	36	16	6	..

The alkali-soluble inorganic phosphorus which is presumably mainly iron phosphate, ranged from 27 per cent to 65 per cent of the total and proved to be the highest single fraction in four of the soils. The highest value was

from the Peterborough soil (A 3246-7) which was included in this series because it gave unusually high citric-soluble phosphorus in relation to its acetic-soluble phosphorus. In spite of the fact that the soil contains 17 per cent carbon, it is interesting to find the inorganic phosphorus of the alkali extract almost three times as great as the organic phosphorus. In the most highly organic soil of the series (A 3560-1) the organic and inorganic forms in the alkali extracts were about equal. The two Scottish soils (A 3328 and A 3769) from basic slag experiments on soils ploughed out for Swedes from five or more years under grass showed very similar analyses, with the highest proportion (about two-thirds) of their total phosphorus in the organic form. This would suggest that a considerable fraction of the phosphorus in such grassland soils remains in a very stable and inert form. Although nitrogen would be liberated during the cultivation for Swedes it would appear that little of the organic phosphorus becomes available, since the Swede crops were complete failures except where basic slag was given. It was observed in these field experiments that the residual effects of the basic slag on oats and hay were very small in spite of the very large response in the Swede crop. This has been taken to mean that the oats grown have access to phosphorus which the Swedes cannot utilize. It is, however, possible that some of the organic phosphorus is broken down during the year after ploughing in sufficient amounts to meet the lower requirements of these crops.

The organic phosphorus forms a low portion of the whole in the two soils (Broadbalk and Woburn) which have been cropped for half a century or more with continuous cereals (wheat and barley respectively). On the other hand, the second sample from Broadbalk field, which has a moderate proportion of organic phosphorus, is an acid soil, ploughed out from a grass head land some long time after the experiments on wheat were commenced. These results suggest that the organic phosphorus is built up largely by grass and that it is relatively stable under acid conditions. It is also notable that the Broadbalk farmyard manure plot has a low proportion of organic phosphorus. Apparently the organic phosphorus of farmyard manure is mineralized fairly quickly at least in neutral soils. This has already been pointed out by the author in an earlier communication [Ghani, 1941].

The sulphuric acid-soluble fractions are much lower than the alkali-soluble inorganic fractions, suggesting that the bulk of the phosphorus in most arable soils accumulates as iron phosphates rather than as an apatite.

Summary

The method of fractionation of soil phosphorus by combined acid and alkali extraction as proposed by Dean has been critically examined.

$N/2$ acetic acid has been suggested as a pre-treating agent for the removal of exchangeable bases before alkali extraction and as a solvent for the readily available phosphorus.

Sodium hydroxide extracts more phosphorus than sodium carbonate at the same concentration and at the same soil-solvent ratio.

The amount of phosphorus extracted by alkali increases as the soil-solvent ratio decreases. The increase is relatively small when the ratio is lower than 1 : 100.

Alkali extraction at 100°C. dissolved more phosphorus than at room temperature or at 40°C. but at 100°C. the organic phosphorus compounds are partly decomposed.

Several extractions are necessary to dissolve the whole of the soluble phosphorus at the room temperature. A Pasteur-Chamberland porous candle has been used in the design of an apparatus for repeated extraction of soil.

The use of $2N$ sulphuric acid after alkali has been suggested for the removal of the apatite fraction.

The modified method has been applied to eight soils of different types and the phosphorus fractions interpreted in the light of their past manurial history.

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THE WILD RICE PROBLEM IN THE CENTRAL PROVINCES AND ITS SOLUTION

BY

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(With Plate I)

RICE is by far the most important food crop in the Central Provinces and Berar, occupying 59 lakhs of acres out of the 245 lakhs devoted to crops. The old Chhattisgarh division, comprising the districts of Raipur, Drug and Bilaspur, contains more than 62 per cent of the total rice area in the province. The prevalence of wild rice (*Karga*) as a weed in the *biasi* paddy fields of Chhattisgarh constitutes a serious economic problem. During the period of vegetative growth wild rice is indistinguishable from most of the cultivated varieties and cannot, therefore, be weeded out in time to allow the legitimate crop to tiller and fill in the gaps. In badly infested fields the percentage of wild rice is sometimes as high as 30, but even if the average infestation be taken to be only 3 per cent the loss it causes over 37 lakhs of acres of *biasi* paddy amounts to more than 22 lakhs of rupees every year. Reduction of this loss has been one of the main objects of breeding work in rice since the year 1928 and it has now been attained by the production of early, medium and late ripening purple-leaved hybrids which give good yield. The seedlings of these hybrids (Plate I) are entirely purple and can thus be very easily distinguished from the green *Karga* seedlings. The results of these experiments are summarized below.

Review of literature

An estimate of the loss due to the occurrence of wild rice was made in 1930 by the Director of Agriculture, Central Provinces and Berar, Mr Plymen, who observes that the percentage of wild rice is at times as high as 30 per cent of the standing crop on a cultivator's field. Roy [1921] working in the Central Provinces reports that in the Chhattisgarh tract the amount of loss due to the occurrence of wild rice is sometimes said to be so great as to reduce the outturn of rice by 50 per cent. He suggests that the best method to get rid of wild forms is to grow coloured rice (*Nagkesar*) or adopt transplantation. Salimath [1921] found that in various parts of Belgaon district of the Bombay presidency, the loss due to the occurrence of wild rice varies from 5 to 25 per cent while other places have been found where up to 30 per cent of the grain is lost either before or during reaping. Bhalerao [1930] suggests that the source of infection through soil, irrigation water and seed should be guarded against to obtain the best results.

Experimental results

The incidence of wild rice in *biasi* paddy fields was studied during 1940 and 1941 in 43 villages in Raipur, Drug and Bilaspur districts. In each

FIG. 1
Seedling one month old

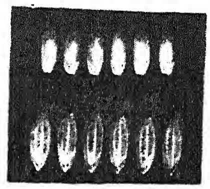

FIG. 2
Cross No. 1
(No. 17 × *Nagkesar*)
Early

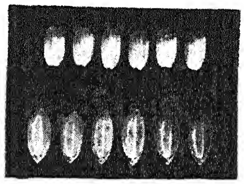

FIG. 3
Cross No. 2
(*Nagkesar* × *Bhondu*)
Medium ripening

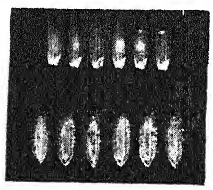

FIG. 4
Cross No. 5
(*Nagkesar* × *Luchai*)
Late

Rice hybrids for fields infested with wild rice

village, ten fields were taken at random and the population of wild and cultivated rice plants was recorded, at the flowering stage during the months of September and October, in three quadrates per field. The size of the quadrate was 4 ft. 8 in. square or 1/2000th of an acre. The results are given in Table I.

TABLE I

Average percentage of wild rice in biasi *paddy fields*

Tahsil	Village	Average percentage of wild rice	Tahsil	Village	Average percentage of wild rice
Raipur	Dongitarai	41	Bilaspur	Badri	17
	Piprod	42		Sakri	17
	Chipridih	54		Barpali	18
	Patewa	55		Hafa	18
				Sarseni	20
Balodabazar	Sonpuri	9		Motia	21
	Balodabazar	14		Jalso	25
	Sukla	16		Khaira	28
	Bharsela	17		Semartal	35
				Koni	36
Dhamtari	Deoni	6		Gatauri	37
	Gokulpur	7		Sendri	37
	Karetha	7			
			Janjgir	Andi	4
Mahasamund	Atharagudi	6		Charoda	4
	Chinoordih	11			
	Lohroad	12	Katghora	Solara	5
	Nawapara	12		Maheshpur	6
	Chote Temri	23		Bendarkona	7
	Bitangipali	27		Kenadand	8
	Bhatori	27		Chakomar	9
	Basna	31			
			Drug	Matwari	44
				Janjgiri	44
			Bemetara	Chuchrungpur	5
				Bahera	6
				Basna	7

The percentage occurrence of wild rice varies very widely from as low as 4 to as high as 55. Generally speaking, wild rice occurs more on the lighter soils than on the heavier ones.

A field-to-field study of the occurrence of wild rice was made in Jora village, adjoining Labhandi farm in Raipur district. In each of the 1,315 fields sown with rice, two quadrates (each 4 ft. 8 in. square) were taken at random and the number of plants of wild and cultivated rices in each quadrate recorded. The average percentage of wild rice for the entire village worked out to be three.

In a similar field-to-field study made in 1,843 paddy fields of Borsi village in Drug district and 480 fields of Darri village in Bilaspur district, the average percentage of wild rice for the entire village, in both the cases, was again found to be three. These observations were made in October when the crop was in ears and much of the wild rice had already been removed by weeding.

If the lowest estimate of loss due to the occurrence of wild rice is taken at only 3 per cent of the yield, the standard outturn at 661 lb. of cleaned rice per acre and the wholesale price of rice at Rs. 2-8 per md. of 82 lb., the loss in yield to the cultivators of Raipur, Drug and Bilaspur districts, where 37 lakhs of acres are under *biasi* paddy, amounts to 22 lakhs of rupees every year. The loss would be much more at the present high prices. To this have to be added the weeding charges for the removal of wild rice which at six annas per acre would amount to another 14 lakhs of rupees. The third weeding which is given at the flowering stage is only for the removal of wild rice.

Reduction of this loss has been one of the main objects of breeding work in rice since the year 1928. It has been stated that wild rice has a green or purple leaf-sheath like most of the cultivated varieties and so is indistinguishable from them and cannot be weeded out. It is recognized after the flowering stage by the presence of long stout awns, blackish grains and red kernels. On account of its characteristic nature of shedding the grains completely, its seed cannot be collected. It thus gets self sown and increases from year to year. The presence of wild rice in the field is a constant source of contamination and brings about a deterioration of the cultivated variety due to natural cross pollination. In an attempt to control the spread of wild rice the farmers sow varieties with green and dark purple leaf-sheath in alternate years or grow *Parewa*, a variety which has dark purple auricles to distinguish it from wild rice, but this variety, comparatively speaking, is a poor cropper.

An attempt was, therefore, made to combine the dark purple auricles of *Parewa* with the commercial variety *Budhiabako* and the high yielding *Bhondu*. The crosses were made by the writer in October 1928 at the Agricultural Research Institute, Nagpur, and the F_1, F_2 and F_3 generations studied in 1929 and succeeding years. Further details about this work will be found in another paper on 'Inheritance of Characters' to be published. Promising hybrids possessing the desired combination of characters were secured in the F_4 generation in 1932. The fixed hybrids in the F_5 and F_6 generations were tested for yield against the parents in Latin Square during 1933 and 1934 at Raipur and in randomized blocks in subsequent years. The results are summarized in Tables II and III.

TABLE II

Yield of cross No. 116 (Bhondu × Parewa) *compared with the parents, Raipur*

Strain	Mean yield in lb. per acre					
	1933	1934	1935	1936	1937	Average
Cross No. 116	3844	2846	3013	2905	3061	3134
Bhondu	3071	2543	2986	2683	2961	2849
Parewa	3332	2442	2450	2355	2478	2611

Biasi—a method of rice cultivation which consists of broadcasting the seed followed by ploughing to thin out the seedlings when they are a foot high

On an average of five years, Cross No. 116 (*Bhondu* × *Parewa*) has given 10 per cent higher yield than *Bhondu* (which was so far the most prolific variety) and 20 per cent higher yield than *Parewa*.

TABLE III

Comparison of cross No. 19 (Budhiabako × Parewa) *with* Budhiabako

Strain	Mean yield in lb. per acre							
				Unmanured				
	1935	1936	1937	1938	1939	1940	1941	Average
Cross No. 19 . . .	2829	2205	2932	1572	1497	1461	1323	1974
Budhiabako . . .	2453	2932	2527	1603	1411	1175	1375	1925

The average results of all the seven years show that Cross No. 19 is as good as the higher yielding parent *Budhiabako* and has the added advantage of being readily distinguished from wild rice.

These trials were simultaneously extended to Government farms at Chandkhuri, Drug and Bilaspur and finally the hybrids were tested on an extensive scale on the cultivators' holdings from 1937 onwards.

In trials now extending over nine years, cross No. 116 (*Bhondu* × *Parewa*) has proved to be the highest yielding strain in the province. Similarly, cross No. 19 (*Budhiabako* × *Parewa*) is the highest yielding strain among medium-fine varieties. Both of them possess dark-purple auricles which distinguish them from wild rice in the seedling stage. These hybrids are now under distribution from all the seed farms in Chhattisgarh and have become very popular. A description of the hybrid strains is given in Appendices A and B.

A more complete solution of the wild rice problem was attempted in 1934 when most of the improved rice strains were crossed with *Nagkesar*, a variety which possesses leaves and stem of purple colour by virtue of which it can be easily distinguished from wild rice. Unfortunately, the yield of *Nagkesar* is very low and its rice is generally red. The crosses of *Nagkesar* with No. 17 *Bhondu*, *Budhiabako*, *Gurmatia* and *Luchai* were raised in the F_1 generation in 1935 and the F_2 and F_3 generations studied in succeeding years. The study of the inheritance of economic characters in these crosses will form the subject of a separate paper. Early, medium and late ripening strains possessing purple leaves to distinguish them from wild rice in the seedling stage were secured in the F_4 generation in 1938 and they were tested for yield against the parents in randomized blocks. The results are summarized in Table IV.

TABLE IV

Yield of purple-leaved hybrids compared with the parents, Raipur

Strain	Mean yield in lb. per acre (Unmanured)				Remarks
	1939	*1940	*1941	Average	
Early					
Cross No. 1 (No. 17 × *Nagkesar*)	1478	896	963	1112	*General yields are low on account of inadequate rains
Nungi (No. 17) . . .	1750	640	1056	1149	
Medium					
Cross No. 2 (*Nagkesar* × *Bhondu*)	1680	1388	1250	1439	
Bhondu	2292	1310	1467	1690	
Late					
Cross No. 5 (*Nagkesar* × *Luchai*)	1690	1616	1350	1552	
Luchai	1998	1476	1029	1501	
Nagkesar (Medium) . .	..	1008	1071	1040	

These hybrids were simultaneously tested at the Government farms at Chandkhuri, Drug and Bilaspur and finally they were tried on an extensive scale on the cultivators' holdings in 1940 and 1941. The yields have been satisfactory and this year 16,000 lb. seed of the early, medium and late ripening purple-leaved hybrids has been supplied in 275 villages of Raipur, Drug and Bilaspur districts for multiplication. The advantages of growing these hybrids in fields infested with wild rice are so obvious that no further propaganda will be necessary to secure their natural spread. The seedlings of the hybrids are entirely purple (Plate I) and can thus be very easily distinguished from the green *Karga* seedlings. These hybrids are not expected to deteriorate by natural cross pollination with other green varieties as the purple leaf-blade colour is recessive to green and the first generation hybrids, which will have green leaves, will be weeded out along with wild rice plants. Practically the whole of the annual loss referred to above can now be prevented by growing these hybrids in fields infested with wild rice. A description of the hybrid strains is given in Appendices A and B.

ACKNOWLEDGEMENTS

This work formed part of the programme of the Central Provinces Rice Research Scheme which has been generously financed by the Imperial Council of Agricultural Research.

Summary

The prevalence of wild rice (*Karga*) as a weed in the *biasi* paddy fields of Chhattisgarh constitutes a serious economic problem. During the period of vegetative growth wild rice is indistinguishable from most of the cultivated varieties and cannot, therefore, be weeded out in time to allow the legitimate crop to tiller and fill in the gaps. In badly infested fields the percentage of wild rice is sometimes as high as 30, but even if the average infestation be taken to be only 3 per cent the loss it causes over 37 lakhs of acres of *biasi* paddy amounts to more than 22 lakhs of rupees every year. Reduction of this loss has been one of the main objects of breeding work in rice since the year 1928 and it has now been attained by the production of early, medium and late ripening purple-leaved hybrids which give good yield. The seedlings of these hybrids are entirely purple and can thus be very easily distinguished from the green *Karga* seedlings. Practically the whole of the annual loss referred to above can now be prevented by growing these hybrids in fields infested with wild rice. A description of the hybrid strains has been given.

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APPENDIX A

Rice hybrids for fields infested with wild rice

Cross No. 1 (*Nungi*—No. 17 × *Nagkesar*). A high yielding early strain suitable for unprotected high lying areas and unirrigated fields infested with wild rice. Seedlings entirely purple and very easily distinguishable from green *Karga* seedlings. Ripens in the 3rd week of October, (sowing time—middle of June). Average yield, 1939 to 1941, (unmanured) 1,100 lb. per acre.

Cross No. 2 (*Nagkesar* × *Bhondu*). A medium ripening strain with leaves and stem of purple colour to distinguish it from wild rice. Suitable for all types of irrigated soils. Ripens in the 2nd week of November. Very good yielder. The paddy is reddish-brown and the rice is coarse and white. Average yield, 1939 to 1941, (unmanured) 1,450 lb. per acre.

Cross No. 5 (*Nagkesar* × *Luchai*). A high yielding late strain with an erect habit of growth and comparatively free from lodging. Suitable for irrigated tracts and heavy soils or low lying areas infested with wild rice. Leaves—purple. Ripens in the 4th week of November. Average yield, 1939 to 1941, (unmanured) 1,550 lb. per acre.

Cross No. 19 (*Budhiabako* × *Parewa*). This is the highest yielding strain among medium-fine varieties and is well suited for irrigated tracts. It has dark purple auricles to distinguish it from wild rice. It is late and is harvested in the 3rd week of November. The rice is translucent and is sold in the market under the trade name of *Hansa*. Average yield, 1937 to 1941, (unmanured) 1,750 lb. per acre. It has become very popular in Chhattisgarh under the name '*Kanthi Budhiabako*'.

Cross No. 116 (*Bhondu* × *Parewa*). This is the highest yielding strain in the Province and is much liked by people who prefer bulk to quality. It ripens in the 2nd week of November and is suitable for all types of soils protected by irrigation. It has dark purple auricles to distinguish it from wild rice. The paddy is reddish brown and the rice is coarse and white suitable for the preparation of puffed and shredded rice. Average yield, 1937 to 1941, (unmanured) 2,000 lb. per acre. It gives 10 per cent higher yield than *Bhondu* which was so far the most prolific variety.

(General yields during 1940 and 1941 are low on account of inadequate rains)

APPENDIX B

Rice hybrids for fields infested with wild rice

Description of morphological characters
(*Rice Research Station, Raipur*)

Characters	Cross No. 1 No. 17 × *Nagkesar* (Early)	Cross No. 2 *Nagkesar* × *Bhondu* (Medium)	Cross No. 5 *Nagkesar* × *Luchai* (Late)	Cross No. 19 *Budhiabako* × *Parewa* (Late)	Cross No. 116 *Bhondu* × *Parewa* (Medium)
Coleoptile	Dark purple	Dark purple	Dark purple	Purple	Purple.
Leaf sheath	Full purple (9) (P. Purple V. L. purple)	Full purple (9) (P. purple V. L. purple)	Full purple (9) (P. Purple V. L. purple)	Light purple (7) (P. L. Purple V.L. purple)	Light purple (7) (P. L. Purple V. L. purple)
Sheath axil	Purple (P. Purple V. White)	L. purple (P. L. Purple V. White)	L. Purple (P. L. Purple V. White)	Purple (P. Purple V. Purple)	Purple (P. Purple V. Purple)
Internode	Light green (1)	L. Yellow (2)	Light green (1)	Light green (1)	Light Yellow (2)
Leaf junctura	Green, mid-rib purple	Purple	Green, mid-rib purple	Dark purple	Dark purple
Auricle	Purple	Purple	Purple	Dark purple	Dark purple
Ligule	Purple	Purple	Purple	White	White
Pulvinus	Green, purp. spots	Green, purp. spots	Green, purp. spots	Dark purple	Dark purple
Septum	Cream	Light brown	Cream, purp. spots	Purple	Brown
Leaf blade	Purple (3)	Purple (3) Broad	Purple (3)	Green	Green, Broad
Glumes, early stage	Purple Short	Purple Short	Purple Short	White Short	White Short
Glumes, ripe stage	L. purple	L. purple	L. purple	White	White
Lemma and palea early stage	Light green, black spots (D)	Reddish orange (M)	L. purple, dark furrows (B)	Light green (F)	Reddish orange (M)
Lemma and palea ripe stage	Straw, black spots (d) Ordinary hairy	Reddish brown (m) Ordinary hairy	Brown furr. (b) Ordinary hairy	Straw (f) Ordinary hairy	Reddish brown (m) Ordinary hairy
Apiculus	Purple (G)	Purple (G)	Purple (G)	L. purple (F)	Purple spr.
Stigma	Dark purple	Dark purple	Dark purple	Dark purple	Dark purple
Awns	Absent	Absent	Absent	Absent	Absent
Habit	Spreading	Spreading	Erect	Spreading	Spreading
Straw	Weak	Weak	Strong	Weak	Weak
Panicle	Well ex. Com. Droop	Well ex. Com. Droop	Well ex. Com. Droop	Well ex. Com. Droop	Well ex. Com. Droop
Rice, size	Medium	Coarse	Medium	Med.—fine	Coarse
Rice, colour	White	White	White	White	White
Rice, scent	Absent	Absent	Absent	Absent	Absent
Rice, endosperm	Translucent with abd. wh.	Abdominal white	Translucent with abd. wh.	Translucent with abd. wh.	Abdominal white

(B, D, 1, 3, etc. refer to coloured plates in " The description of crop-plant characters and their ranges of variation Rice ". *Indian J. agric. Sci.* VIII, V, Oct. 1938)

RICE HYBRIDS FOR FIELDS INFESTED WITH WILD RICE

Description of quantitative characters
(Average of 3 years, 1939 to 1941)

Characters	Cross No. 1 No. 17 × *Nagkesar* (Early)	Cross No. 2 *Nagkesar* × *Bhondu* (Medium)	Cross No. 5 *Nagkesar* × *Luchai* (Late)	Cross No. 19 *Budhiabako* × *Parewa* (Late)	Cross No. 116 *Bhondu* × *Parewa* (Medium)
Height of plants	106·2 ±2·101	135·4 ±1·519	117·5 ±1·330	115·4 ±1·906	111·3 ±1·451
Number of tillers per plant	1·80 ±0·143	1·77 ±0·135	1·91 ±0·173	2·17 ±0·195	1·73 ±0·149
Flowering date	19 Sept.	14 Oct.	21 Oct.	15 Oct.	13 Oct.
Days from sowing to flowering	96 ±0·136	121 ±0·409	128 ±0·305	122 ±0·349	120 ±0·325
Ripening date	14 Oct.	14 Nov.	25 Nov.	16 Nov.	10 Nov.
Days from sowing to ripening	121 ±0·316	152 ±0·408	163 ±0·577	154 ±0·224	148 ±0·707
Length of panicle cm.	22·72 ±0·680	24·71 ±0·539	21·55 ±0·483	22·18 ±0·471	21·3 ±0·63
Number of grains per panicle	120·0 ±9·296	139·9 ±6·658	179·3 ±9·695	115·7 ±6·67	103·7 ±5·72
Sterility per cent	6·12 ±1·546	11·55 ±1·920	4·38 ±0·979	13·73 ±1·745	14·39 ±1·890
Grain length, mm.	8·46 ±0·043	8·35 ±0·054	7·84 ±0·038	9·22 ±0·038	8·29 ±0·038
Grain breadth, mm.	3·07 ±0·017	3·46 ±0·023	2·69 ±0·017	2·47 ±0·009	3·37 ±0·013
Grain, length/breadth	2·75 ±0·019	2·42 ±0·015	2·91 ±0·021	3·74 ±0·020	2·46 ±0·016
Rice, length, mm.	6·27 ±0·033	5·98 ±0·043	5·64 ±0·028	6·50 ±0·065	5·89 ±0·030
Rice, breadth, mm.	2·55 ±0·012	2·90 ±0·015	2·20 ±0·011	2·03 ±0·008	2·86 ±0·013
Rice, length/breadth	2·45 ±0·012	2·07 ±0·018	2·58 ±0·024	3·20 ±0·047	2·06 ±0·016
Weight of 1000 grains, gm.	26·64 ±0·093	29·22 ±0·056	19·37 ±0·083	19·97 ±0·086	29·08 ±0·044
Weight of 1000 kernels, gm.	19·55 ±0·077	22·11 ±0·038	14·19 ±0·037	14·86 ±0·047	22·44 ±0·039
Yield per plant, gm.	5·32 ±0·231	5·59 ±0·322	5·25 ±0·327	4·35 ±0·204	5·17 ±0·310
Milling quality. Whole rice per cent	51·57 ±1·414	52·87 ±3·668	44·94 ±3·374	50·67 ±1·915	42·94 ±1·648
Broken rice per cent	19·27 ±1·049	19·67 ±2·288	21·93 ±4·267	15·93 ±2·662	26·13 ±1·176
Husk and bran per cent	29·16 ±0·619	27·46 ±1·443	33·13 ±0·671	33·40 ±1·245	30·98 ±0·532

STUDIES IN INDIAN CEREAL SMUTS

V. MODE OF TRANSMISSION OF THE KARNAL BUNT OF WHEAT

BY

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INTENSIVE work on the Karnal bunt of wheat due to *Neovossia indica* (Mitra) Mundkur is in progress at New Delhi since 1938. The primary object of this investigation has been to determine the mode of transmission of this disease. Without a precise knowledge of the manner in which it is disseminated from place to place and carried over from year to year, and of the methods by which it can be induced in experimental pots and plots, it is hardly possible to devise seed treatments or to develop resistant varieties. The bunt which was first discovered at Karnal is very common in parts of the Punjab and the North-West Frontier Province and reports of its occurrence in Saharanpur, a district of the United Provinces adjacent to the Punjab, have been recently received.

Since the inception of this work attempts have been made year after year to improve the technique so as to induce the appearance of the disease in infested pots. In the numerous pot experiments conducted during the past four years, only a single infected ear in 1941 and five infected ears in 1942 have been observed. The ear observed in 1941 was from an infested pot but of the five ears observed in 1942, two came from infested pots and three from controls. In all the other cases, the experiments have been a total failure.

METHODS OF EXPERIMENTATION

Soil. Soil for these experiments was obtained from two sources, one being a field at Karnal where the disease had appeared in an epidemic form and the other a wheat field of the botanical section at New Delhi where bunt, as a rule, does not appear. It was sieved and manured before use and after setting apart a portion for the control pots, the rest was infested by bunt spores. This was done in the following manner. A thick suspension of spores that had been collected the previous season at Karnal was prepared. This suspension was black in colour due to the abundance of the spores. It was then thoroughly mixed with the soil and the soil was placed in pots. The pots were kept moist by sprinkling water over them and they were either placed indoors, or kept covered. Commencing 1939, some of the experimental pots were buried up to the brim in a field near the mycological section. Occasionally the pots were watered with suspensions of spores and the soil in them stirred.

Seed. Seeds from bunted ears (Imperial Pusa 165) were carefully examined to see if they were infected by the disease. Those seeds which showed the presence of the *sori* in their crease end were selected ; for the control pots, however, healthy seeds from non-bunted ears were chosen after examination with a hand lens for freedom from disease.

Spores. Bunted ears were dipped in clean water and vigorously rubbed so as to liberate the spores. When almost all the spores had been released, the husk was separated and the seed was collected, dried and stored for later use. The spores were allowed to settle down, the supernatant liquid was decanted and the spores were collected, air dried thoroughly, placed in vials and stored at a temperature of about 15°C. A large quantity of spores was collected each year in this manner.

For germinating the spores, they were first soaked in water for six days. On the seventh day, they were spread on a filter paper. This filter paper was then placed in a large petri dish and incubated at about 20°C. On the third day, the spores were found to put forth germ tubes and sporidia. Wheat seeds soaked in water for 24 hours, were then placed on the moist filter paper with the germinating spores and incubated at 20°C.

In 1941, the method of germinating the seed was slightly altered. An abundant quantity of spores was mixed with clean sand. The mixture was moistened, placed in a large dish in a room (where temperature ranged from 10°C. to 15°C.) at the end of September. The seed was germinated in this sand in the usual manner.

Experiments in 1938-39

These experiments were carried out in 25 pots of 3 in. diameter with Delhi soil. Fifteen pots were filled with heavily bunt-infested soil and 10 pots served as controls. The soil was infested and the pots filled on 5 October 1938. Infested seed was sown in all the pots on the 28th of the month. Three seeds were sown in each pot.

Growth of the plants was satisfactory and the ears were harvested at the end of March. They were then carefully examined for the presence of bunt but none of the ears showed the disease.

Experiments in 1939-40

Experiments on a more comprehensive scale were designed for 1939-40. In one set of experiments glazed pots of 12 in. diameter were buried up to the brim. Twenty-four of these pots were filled with Karnal soil that had been heavily re-infested. Sterilized Karnal soil was placed in six other pots. Another 12 pots were filled with Delhi soil of which six alone were infested with bunt spores. Soil was infested on 5 September 1939 and a second heavy suspension was added on the 15th of the month. The pots were kept moist and covered. The sowing plan is shown in Table I.

Bunt-free seed was sown in horizontal rows number I, III and V and infested seed was sown in the rest of the pots. Seed in the pots in the vertical row *a* was sown on 1 November 1939, vertical row *b* on 4 November and so on until 16 November. Ten germinated seeds were sown in each pot.

TABLE I

Sowing plan of infected and control pots

Nature of the soil	Pot numbers						
	a	b	c	d	e	f	Remarks
I—Karnal soil, re-infested	1	2	3	4	5	6	Bunt-free seed
II—Karnal soil, re-infested	7	8	9	10	11	12	Bunted seed
III—Karnal soil, re-infested	13	14	15	16	17	18	Bunt-free seed
IV—Karnal soil, re-infested	19	20	21	22	23	24	Bunted seed
V—Karnal soil, sterilized	25	26	27	28	29	30	Bunt-free seed
VI—Delhi soil, infested	31	32	33	34	35	36	Bunted seed
VII—Delhi soil, non-infested	37	38	39	40	41	42	Bunted seed

Growth was satisfactory and the ears were harvested on 30 March 1940. They were carefully examined for the presence of bunt but none of the grains was bunted.

In another experiment, the glazed pots used were of 6 in. diameter but they were not buried. They were filled with heavily infested Karnal soil as before and infested seed which, however, was not germinated was sown in all of them on 6 November at the rate of five seeds per pot. The depth at which the seed was sown was, however, different. The time taken by the radicle to emerge out of the soil depends to a certain extent on the depth of sowing. If this time is prolonged, then it is likely that the spores have a better chance to infect the seed. In one set of five pots, the seed was sown at a depth of half-an-inch, in a second at one, in a third at two, in a fourth at three, and in the fifth and the last at four inch depth. The growth of the plants was satisfactory and the ears were harvested on 29 March 1940. None of the grains showed bunt.

Experiments in 1940-41

The number of buried 12 in. pots was increased to 70 but the plan of soil infestation was as before. Instead of six as in previous year, the number of vertical rows was ten. Sowing in the first vertical row was done on the 29 October and continued in the rest of the rows on every fourth day until 25 November 1940.

Growth of the plants was satisfactory and the plants were ready for harvest on 13 April. The ears from each pot were separately collected and both the ears and the grain from them carefully examined for the presence of bunt. One diseased ear, of which four grains were completely bunted and seven partially bunted, was found in horizontal row III and in the pot sown on November 10. This pot had been filled with infested soil. None of the other ears was bunted.

In another experiment in 6 in. pots, 60 pots were filled with heavily infested Delhi soil and infested seed which had not been germinated in petri dishes was sown, at the rate of five seeds per plot, on 22 November. McAlpine [1910] states that if oat plants are cut back before heading time and induced

to tiller, these tillers usually show heavier infestation by loose smut. Hoping that such cutting back might induce bunt, plants in one lot of eight pots were cut back on 10th in a second lot on 20th and a third lot on 30th December, respectively. The rest served as controls. The ears were harvested on 8 April 1941. They were carefully examined but none of the ears was bunted.

Experiments in 1941-42

The tests in the 70 buried pots were repeated in 1941-42. Two infested ears were found in horizontal row IV, sown on November 16 and three in two pots in horizontal row V, sown on November 16 and 19, respectively. In this latter row, the pots were filled with sterilized Karnal soil and healthy seed had been sown. In all the rest of the pots, there was no bunt.

Discussion of results

The results presented above furnish overwhelming evidence which leads to the conclusion that the Karnal bunt is neither seed-borne or soil-borne. In the course of these experiments, naturally-infested seed was sown in bunt-infested soil and disease-free soil; and bunt-free seed was sown in soil heavily-infested with bunt spores. In addition, naturally-infested seed which was germinated in the presence of germinating spores was also sown in heavily-infested soil. In almost all cases, however, negative results have been repeatedly obtained. In 1941, one infested ear was found in a pot which contained infested soil and two such ears were found in 1942. As against these, three ears were found in 1942 in pots containing soil free from bunt, in which disease-free seed had been sown. It appears to be more than likely that this is natural infection but how such infection takes place in nature, it has not been possible to ascertain. It does not seem to be via the seed or the soil. Along with the head smut of maize [*Sorosporium Reilianum* (Kuehn) McAlpine], the long smut of *jowar* [*Tolyposporium Ehrenbergii* (Kuehn) Patouill.] and certain other smuts, the mode of transmission of this smut will also have to remain a mystery for the time being.

In the loose smut of wheat [*Ustilago Tritici* (Persoon) Rostrup] infection is floral and it takes place at the time of anthesis. But at the time the stigmas are in a receptive state, the spores of the smut are already present in great abundance, for smutted ears appear a little earlier than the flowers. In the case of Karnal bunt, the disease does not become manifest until the ears are mature and ready for harvest at which time there are no wheat flowers at all. There is, therefore, little likelihood of infection being floral.

Is it safe then to recommend seed treatments to control the disease? When heavily-infested wheat seed has consistently failed to produce the disease in the resulting crop, it appears as though such treatments will not be of much avail.

Summary

The Karnal bunt of wheat (*Neovossia indica*) is prevalent in the Punjab and the North-West Frontier Province and may occur in the north-western districts of the United Provinces.

Attempts have been made to bring about this disease in pot experiments since 1938. Disease-free seed was sown in heavily-infested soil and bunted seed sown in disease-free soil and also heavily-infested soil. Bunted seed was also sown in infested soil at different depths. Plants raised from bunted seed in infested soil were cut back to induce tillering with the hope that bunt would appear in the tillers. In almost all cases completely negative results have been obtained.

Throughout the course of these experiments, three bunted ears appeared in infested pots but they also appeared in control pots that contained disease-free soil and were sown with disease-free seed. These few cases appear to be natural infections but it has not yet been possible to ascertain how such infection takes place in nature.

REFERENCE

McAlpine, D. (1910). *The Smuts of Australia*. Melbourne

PROPERTIES OF SYNTHETIC MIXTURES OF COLLOIDAL SOLUTIONS OF SILICIC ACID AND ALUMINIUM HYDROXIDE, I*

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(With two text-figures)

PREVIOUS investigations from this laboratory [Mukherjee, *et al.* 1937; Mitra, 1936, 1940; Mitra *et al.* 1940; Chatterjee, 1939] show that colloidal solutions of some hydrogen clays resemble silicic acid so far as they show in common an inflexion point in the acid region when titrated with bases. The total acidity depends on cation effects.** The present investigations on the properties of mixed gels have been undertaken on the lines of the work on hydrogen clays, pure gels and pure minerals which has been done in this laboratory.

Bradfield [1923] studied the physico-chemical properties of a synthetic mixture of purified aluminium hydroxide, ferric hydroxide and silicic acid having the same composition as the colloidal material isolated from a heavy clay subsoil. He observed that the natural clay considerably differs from the artificial mixtures as regards (*i*) velocity of migration in an electric field; (*ii*) buffer action towards alkalis; (*iii*) flocculation; and (*iv*) the amounts of Al, Fe and Si brought into solution by acids and alkalis. The synthetic sol was positively charged while the natural colloid was negative. The former showed a stronger buffering towards alkalis than the latter and was most readily flocculated by polyvalent anions in the alkaline medium; the natural colloid was, on the other hand, most sensitive to multivalent cations in an acid medium. The artificial mixture was more soluble in dilute acids and alkalis than the natural clay. From these observations he concluded that there were differences between the two regarding their chemical constitution. Mattson [1928, 1930] prepared synthetic systems by mixing increasing amounts of sodium silicate solution with aluminium chloride solution and obtained successively an electro-positive, an iso-electric precipitate and finally with an excess of silicate an electro-negative sol. A series of iso-electric precipitates

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* The results have been published in the Annual Report for 1939-40 on the working of a scheme of Research into the Properties of Colloid Soil Constituents financed by the Imperial Council of Agricultural Research. A Note on this subject has been published in the Proceedings of the Indian Science Congress Association, 1941.

** The total acidity has been found to depend on (*i*) pH and (*ii*) the nature of the base with which the sol is titrated.

were also prepared in which the proportion of silica decreases with an increase in the iso-electric *p*H approaching zero at *p*H 7·0. It was found that the molecular ratio between the constituents reaches a maximum but remains always less than three. The iso-electric *p*H is about five for precipitates of this composition. The amount of silica in the precipitate could be increased by adding suitable cations whereas in the presence of multivalent anions the proportion of alumina is increased. The precipitates are electro-positive in an acid medium and electro-negative in an alkaline medium. Their base exchange capacities increased with the ratio of silica to alumina and were of the magnitude observed with natural soil colloids. Mattson considers that silicate ions enter into the sesquioxide complex and lowers the iso-electric *p*H as a result of the displacement of diffusible anions including hydroxyl ions by the silicate ions.

Bhattacharya and Ganguly [1936] and Bhattacharya [1937] have studied gels of silica, alumina and ferric oxides and their mixtures. They observed that the mixed gels adsorbed cations in excess of that calculated for their components. The pure gels take up most water when saturated with Na, whereas the mixed gels have the greatest capacity when saturated with Mg. The retention of water was at a maximum at a silica-sesquioxide ratio of 1·4. Mixed gels containing SiO_2 and Al_2O_3 or Fe_2O_3 saturated with various cations have cataphoretic velocities in the order Na $>$ K $>$ Mg $>$ Ca $>$ H and the reverse order was observed for mixed gels containing Al_2O_3 and Fe_2O_3.

Anderson and Byers [1936] titrated a mixed gel of aluminium hydroxide and silicic acid with caustic soda. Their titration curve shows a weak acid character and a strong buffer action in the region of *p*H 6·5.

TABLE I

Changes in the p*H and specific conductivity of the mixed sols with time*

Systems*	Colloid content gm. per litre	*p*H			Specific conductivity $\times 10^5$ mho		
		After 24 hrs.	After 1 week	After 3 weeks	After 24 hrs.	After 1 week	After 3 weeks
1 Silicic acid sol .	5·87	4·10	4·09	4·10	1·63	1·60	1·62
2 Mixed sol 2 : 1 .	5·88	4·09	4·05	..	2·71	3·45	4·50
3 Mixed sol 1 : 1 .	5·88	4·20	4·53	4·64	2·38	2·62	3·52
4 Mixed sol 1 : 2 .	5·88	4·51	4·82	4·76	2·20	2·32	3·20
5 Aluminium hydroxide sol	5·88	6·20	6·25	6·24	2·80	2·86	2·82

* Molar ratios of SiO_2/Al_2O_3

Sols of silicic acid and hydrous alumina were prepared and purified in the same manner as previously described [Mukherjee *et al.* 1934, 1936; Chatterjee, 1939]. Three synthetic mixtures were prepared by adding increasing amounts of colloidal hydroxide to a definite volume of silicic acid sol. Mutual coagulation took place as shown by the presence of flocks but no appreciable sedimentation was observed till about three weeks had passed. In view of the heterogeneous character of the resulting mixture it was thought desirable to study the variations in the *p*H and specific conductivity of the mixed sols with time. The results are shown in Table I.

The data cited above show that the *p*H and specific conductivity of the synthetic mixtures change with time. The variations show the presence of a slow interaction between colloidal silicic acid and aluminium hydroxide-

Interaction with alkalis

The free and total acids of the synthetic mixtures as also those of colloidal silicic acid and aluminium hydroxide are given in Table II. The total acids have been calculated both at inflexion points and at *p*H 7·0 in the titration curves.

TABLE II

Free and total acids of the mixed sols

System	*p*H	Free acidity $\times 10^5 N$	Total acidity $\times 10^5 N$ At inflexion point	Total acidity $\times 10^5 N$ At *p*H 7·0	*p*H at inflexion point
1 Silicic acid sol .	4·09	8·1	16·0	37·0	4·9
2 Mixed sol 2 : 1 .	4·05	8·9	78·0 (17·0)*	78·0	7·0 (4·5)*
3 Mixed sol 1 : 1 .	4·50	3·0	77·0	72·0	7·2
4 Mixed sol 1 : 2 .	4·82	1·5	78·0	67·0	7·4
5 Aluminium hydroxide sol	6·20	0·09	..	16·0	..

* At first inflexion point (*p*H 4·5)

The potentiometric titration curves (Fig. 1) of the mixtures with NaOH do not resemble those of either the aluminium hydroxide or the silicic acid sols and show definite inflexion points between *p*H 6·5 and 7·5 as observed in the titration curves of some hydrogen clay and bentonite sols [Mukherjee, *et al.* 1937; Mitra, *et al.* 1940]. The mixture having $SiO_2 : Al_2O_3$ ratio of 2 : 1 shows two inflexion points, one in the acid region (*p*H 4·5) as observed with

silicic acid sols [Chatterjee, 1939]. As the percentage of silica in the mixture increases the inflexion point found between pH 6·5 and 7·5 gains in sharpness.

The amounts of acid neutralized at pH 7·0 also increase with the silica contents of the mixtures. At the inflexion point, however, they do not differ widely from one another but the pH at inflexion point slightly decreases with increasing silica content.

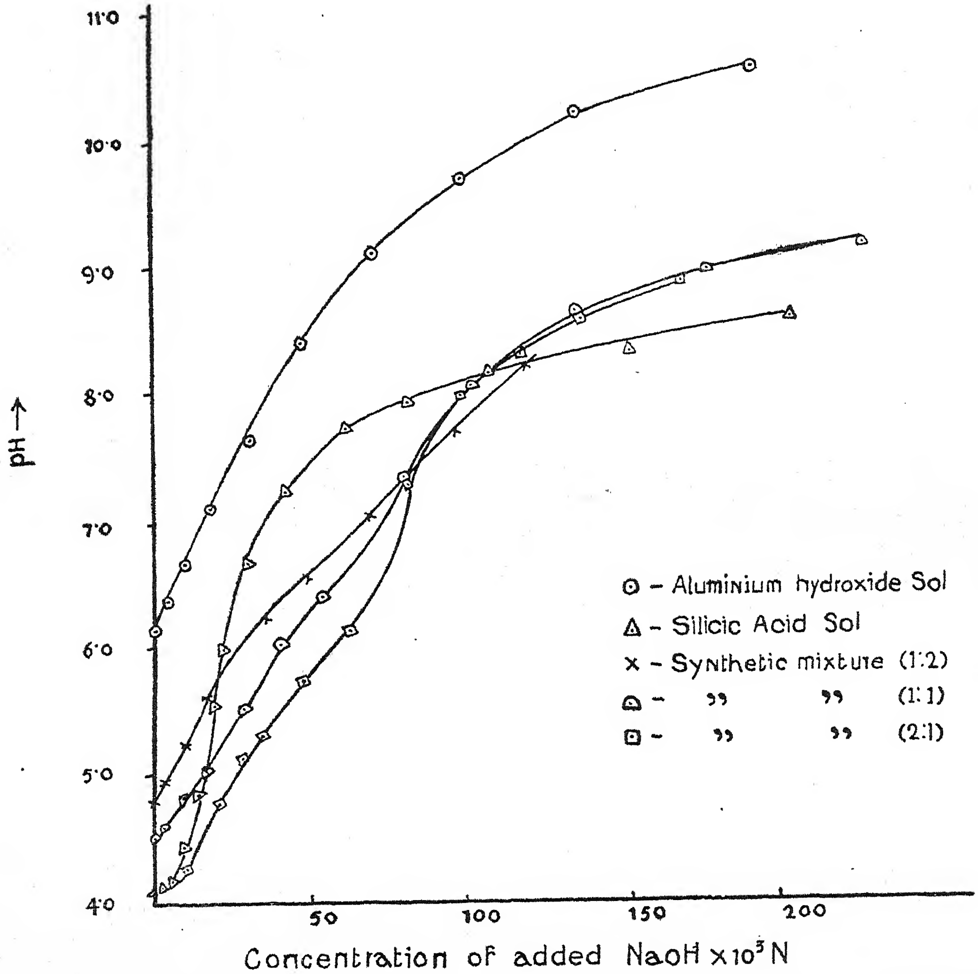

FIG. 1. Potentiometric titration curves of the synthetic mixtures as also those of colloidal silicic acid and aluminium hydroxide with sodium hydroxide

BUFFER CAPACITY

The buffer capacities ($\triangle B/\triangle p$H) at different points in the titration curves of silicic acid sol, synthetic mixtures and colloidal aluminium hydroxide are plotted against the concentration of added alkali in Fig. 2. The buffer capacity curves of the mixtures do not resemble those of either silicic acid or aluminium hydroxide sols. The buffer capacity calculated by adding those

of the individual components at a given concentration of the alkali, is considerably higher than that obtained with synthetic mixtures.

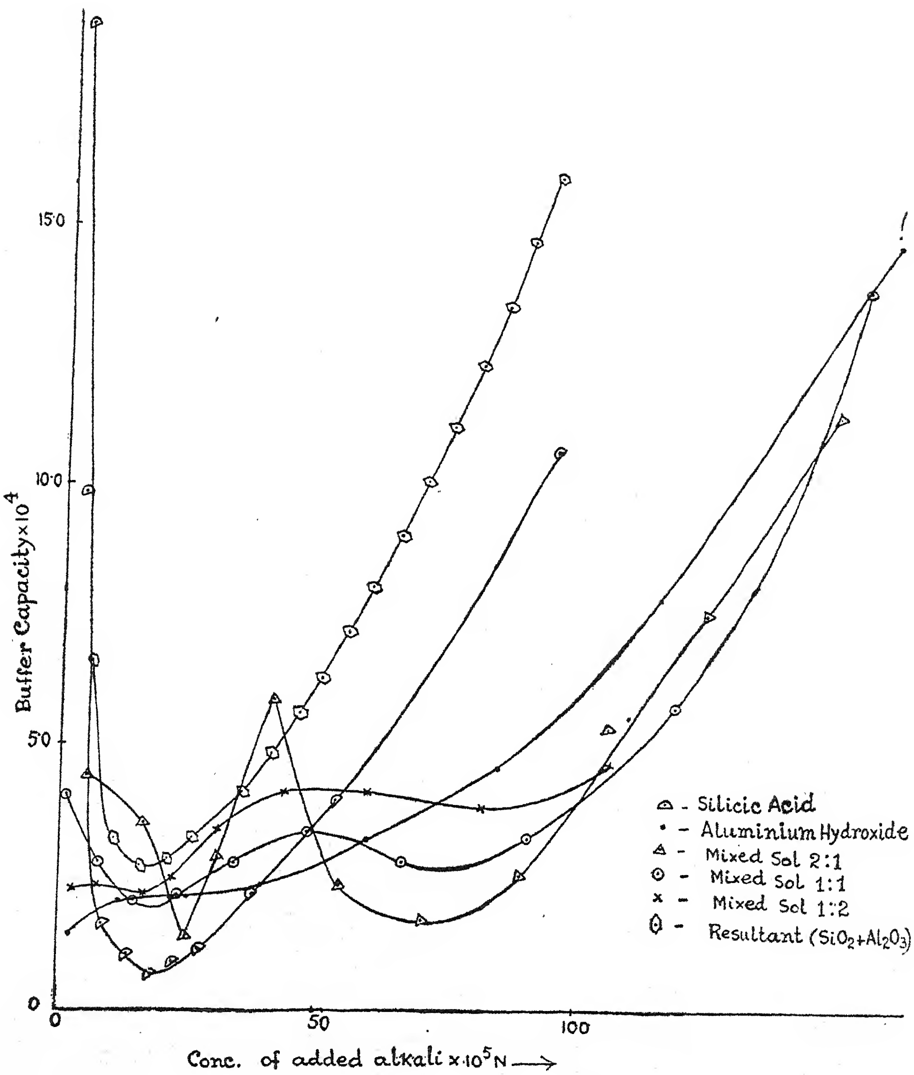

FIG. 2. Buffer capacity curves of silicic acid sol, synthetic mixtures and colloidal aluminium hydroxide

CHARGE MEASUREMENTS

The synthetic mixtures used in this work were all electro-positive (Table III). A micro-cataphoretic cell of the Abramson type was used for this purpose.

TABLE III

Sign of the charge of the synthetic mixtures and their appearance under the microscope

System	Sign of charge	Appearance under microscope
1 Silicic acid sol . . .	—	
2 Mixed sol 2 : 1 . . .	+	Number of small particles very few; larger particles move more slowly
3 Mixed sol 1 : 1 . . .	+	Number of small particles few
4 Mixed sol 1 : 2 . . .	+	Small particles are found in greater numbers to collide with the bigger ones and vanish out of sight
5 Aluminium hydroxide sol .	+	

It is interesting to note that the mixture having $SiO_2 : Al_2O_3$ ratio of 2 : 1 is electro-positive. Similar results have been obtained by Bradfield [1923] who found that a mixture having $SiO_2 : Al_2O_3$ ratio of 1·85 : 1 was electro-positive.

SUMMARY

The *p*H and specific conductivity of the mixtures change with time showing the presence of a slow interaction between colloidal silicic acid and aluminium hydroxide.

The potentiometric titration curves of the mixtures with NaOH do not resemble those of either the silicic acid or aluminium hydroxide sols. They show inflexion points between *p*H 6·5 and 7·5.

The total acid of the mixtures calculated at *p*H 7·0 increases with their silica content but at the inflexion points they give almost identical values. The *p*H at inflexion, however, increases with the alumina content.

The buffer capacity curves of the mixtures do not resemble those of colloidal silicic acid or aluminium hydroxide sols.

The synthetic mixtures used in this work were all found to carry a positive charge.

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SOILS OF THE DECCAN CANALS

III. STUDIES ON THE EFFECT OF VARIOUS ROTATIONAL CROPS AND GREEN MANURES ON THE SOIL AND ON THE SUCCEEDING CANE CROP, WITH SPECIAL REFERENCE TO SOIL STRUCTURE

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Introduction

THE value of suitable crop rotations in any system of crop growing for the purpose of maintenance of soil fertility is well known, it being a long-standing experience with farmers in all countries that crops grow better in rotation than in continuous succession. This aspect of agricultural practice assumes an additional importance under the trying conditions of irrigation, farming, and particularly under cane growing, in the Bombay-Deccan where the cane crop remains for a long time on the land. On an examination of the crop rotations ordinarily practised in the tract it was apparent that the success of maintaining soil productivity was largely linked up with the period of rest from cane-growing that each of the rotational systems would provide, those with proportionately longer periods under cane being considered to be exhausting. However, it seems to be quite probable that different rotational crops may have certain pronounced effects on the soil condition. Actually, some of these crops are believed to exert a depressing effect on the yield of the succeeding cane crop. Therefore, in the working out of systems of crop rotations suitable for a general agricultural practice for the canal areas which would ensure the maintenance of soil fertility and of cane yields at a high level it was considered imperative that detailed soil investigations on the effect of crop rotations should be first undertaken.

Historical

The scientific knowledge that can be drawn upon to supply points for guidance for these studies is, unfortunately, rather meagre, except perhaps on the question of green manures as affecting soil fertility. The memorable

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experiment carried out by Boussingault between 1834-41 [Russell, 1937] dealt with various rotations in order to see which was the most efficaceous. From the analyses of the crops and manures applied in each rotation he arrived at the conclusion that, other things being equal, the best rotation is one which yields the greatest amount of organic matter over and above what is present in the manure. But no account was taken of the balance remaining in the soil. The classical investigation of Daubeny in 1845 [Russell, 1937] was conducted mainly from the point of view of testing the hypothesis of the toxic effect of crops on those following them but he was unable to prove the existence of any toxins. He showed that in continuous cropping the decrease in yield was due to the more rapid removal of mineral nutrients required by that particular crop. Since then, although long-continued field experiments with different crops have established the superiority of crops in rotations to continuous cropping [Weir, 1926], no explanation of the exact causes of such differences is yet forthcoming from the point of view of soil studies. A direct approach to soil problems involved in crop rotations is found in the work of Odland and Smith [1933] where they have reviewed the results of the past work in this direction. They have grouped the various hypotheses put forth by different workers for explaining the effect of certain crops on succeeding crops under the following four heads :

(*i*) Crops that remove excessive quantities of mineral elements tend to impoverish the soil for those elements.

(*ii*) Crops that remove the greatest excess of elements that are chemically basic over those that are acidic create the greatest degree of soil acidity and correlated toxicity.

(*iii*) Crops that provide residues relatively high in carbohydrates and low in nitrogen are decomposed by micro-organisms at the expense of soil nitrogen, decreasing the supplies available to crops.

(*iv*) Certain crops may excrete organic toxins from the roots or the decomposition of plant residues may leave organic toxins in the soil temporarily or permanently.

From the results of 25 years' experimentation at the Rhode Island Agricultural Experiment Station these authors were able to find support for the first two hypotheses but no definite conclusions could be drawn regarding the rest, although in the case of corn it was found that the relative nitrogen removal by the preceding crops was correlated with yield. It may be noted in this connection that the explanation offered under (*ii*) above cannot account for the differential effects of rotational crops in the soils under the present study as they are highly calcareous, and changes, if any, introduced by cropping are usually counteracted by the lime reserves in these soils.

The beneficial effects of green manuring by burying in leguminous crops in enhancing the nitrogen contents of soils and the yields of succeeding crops are already too well known and need not be discussed here. It has also been claimed by certain Russian workers [Russell, 1938] that fallowing (where grasses are allowed to grow) and growing of certain leguminous plants help in the building up of a desirable soil structure. But no comprehensive data, especially for Indian soils, on the effects of commonly grown rotational and green manure crops on tilth and other soil properties, are available. It is

proposed to deal with this aspect of the problem in a series of papers in order to arrive at a scientific basis of crop rotations for sugarcane for different soil types in the canal zones of the Bombay-Deccan.

Outline of work

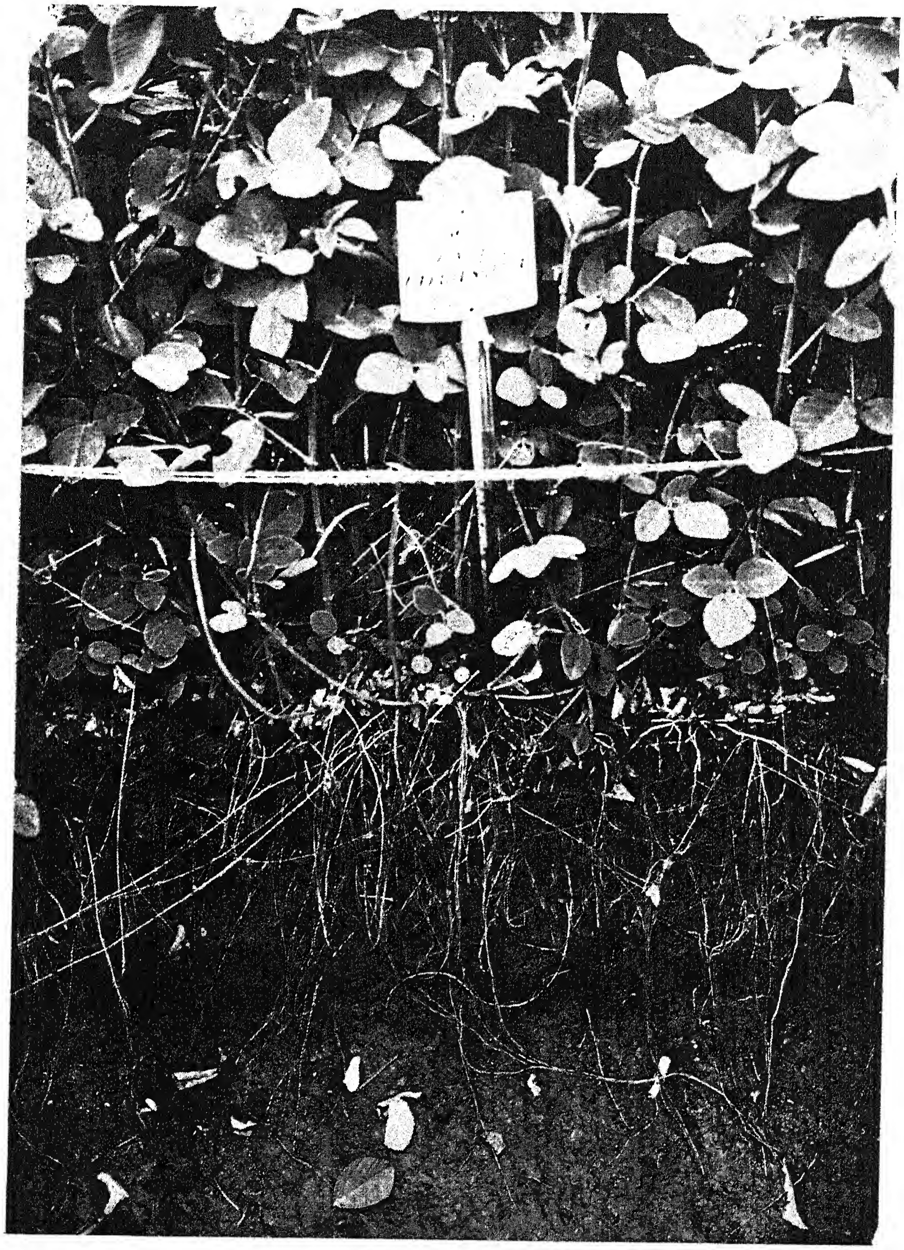
For the purpose of our study three of the more common rotational crops ordinarily grown in the tract, and which were likely to fit into the general economics of agricultural practice, were chosen. These were groundnut, cotton and fodder *jowar* (*Andropogon sorghum*). At the same time, as green manuring has come to be accepted as a standard practice included in sugarcane rotations two of these were included for study. One of them was sunn-hemp (*Crotalaria juncea*) and the other was a leguminous weed locally called *patada shevra* (*Desmodium diffusum*) (Plate II), which was isolated at the station and, in preliminary trials, had shown promise of being a good substitute for sunn under certain conditions. The sixth and last treatment taken up for these studies was fallow, where weeds were encouraged to grow by a few waterings given during dry spells and the green matter ploughed in before the weeds produced seed, so as to avoid trouble by excessive weediness later on. The fallow treatment was included in order to provide a control as well as to meet the needs of certain large-scale cane growers, particularly sugar factories, who do not find it convenient to grow intermediate rotational crops but leave the land fallow allowing natural vegetation to come up. For all practical purposes fallow, therefore, can be considered as a sort of green-manuring treatment and has been treated as such in the following discussions. Sugarcane was grown after these treatments with uniform cultural operations, irrigation and manuring.

In the present investigations, we set ourselves to determine mainly (*i*) the general effect of each of the treatments on the soil and (*ii*) the behaviour and growth of sugarcane immediately following these treatments. Special prominence has, however, been given to the study of soil tilth, as a deterioration of this soil condition is believed to be reflected in the general loss of heart of the soil occurring in cane areas due to exhausting cropping.

Experimental

Field experiment

The following six rotational treatments were laid out according to the randomized block system with four replicates for each treatment :—(1) cotton (2) groundnut (3) fodder *jowar* (4) sunn (5) fallow and (6) *patada shevra*. The gross plot size was 40·8 ft. ×28 ft. (1·04 *guntha* or 2·6 cents). Sufficient room between adjacent blocks and plots was provided to admit of separate cultural operations for the treatments but when cane was grown these intervening spaces were also planted so as to avoid exposure of isolated plots of cane to wind. The central plot, after leaving out a border, measured 36·8 ft. ×20 ft. (0·68 *guntha* or 1·7 cents). The experiment was carried out on the Padegaon farm on a typical black cotton soil designated as 'B' type according to the classification adopted at the station [Basu and Sirur, 1938].



PATADA SHEVRA (*Desmodium diffusum*)
(A new green manuring crop under trial at the Padegaon Station - fully mature crop with the roots exposed)

The *kharif* crops were grown in 1936 according to the usual methods of cultivation followed in the tract. The time of sowing for the various crops occurred between the first week of May (for cotton) to the second or third week of June for *jowar* and groundnut. The number of irrigations varied from three to four for different crops according to their needs. Fallow was irrigated at the time of sowing sunn and then again two or three times during dry weather to encourage weed growth. Regarding the disposal of crops, the green-manuring crops (in which fallow is included) were ploughed under at the flowering stage.

The preparatory tillage for cane excluding the ploughing for green-manure crops which was given at the time of burying the crops, consisted mainly of one ploughing by gallows plough. In the case of green-manuring crops this is usually given in middle to late November when the land comes into condition after the stoppage of the rains; but in the case of rotational crops whose growth period extended beyond the rainy season, e.g. in cotton and groundnut, the ploughing was given soon after harvest of the crops. The period of ploughing for the different crops thus varied between mid-November to early December. This may be taken as the main-tilth-producing operation as the soil is left, subsequent to ploughing, to the weathering action of the atmosphere for about a month or more. The land was then worked with a disc harrow, and finally laid in ridges and furrows for cane planting in January.

Subsequently cane was grown in the season of 1937-38 with identical manurial and cultural operations, the details of which are given later.

Methods employed

The laboratory and field methods followed for determining the various soil properties are described below:

Soil tilth. The method developed by Keen [1931] at Rothamsted for measuring the effect of cultivation implements on the soil was followed for determining soil tilth. Fresh samples of soil from the field were made to pass through a bank of sieves of decreasing mesh size (having, in order, square meshes with length of sides $1\frac{1}{2}$ in., $\frac{5}{8}$ in., $\frac{1}{4}$ in., and finally round holes 3 mm. in diameter) and the fractions so separated were weighed. A single value index for soil tilth on the basis of relative surface area was calculated as recommended by Keen. The method was previously standardized by working on a large number of soil samples and the number of movements to be given to each sieve for effective separation of the fractions was worked out so as to reduce the personal error to a minimum. The determination was also done on a sufficiently large number of replicates so as to reduce the standard error within a reasonable limit.

Dispersion coefficient. This was taken as the ratio of clay obtained by the dispersion of the fresh soil by water alone to the total clay obtained by the International method of mechanical analysis.

Oxygen-giving power. Determined by the change in colour produced in an aqueous solution of 'aloin' by shaking up fresh soil with the solution and comparing the colour with standard 'aloin' solution as recommended by Waksman [1931].

For the sake of economizing space the methods already described in previous publications of the series have not been given here.

Presentation of data and discussion

The rotational crops were grown in the *kharif* season of 1936. The yields of all the crops were satisfactory and are given in Table I.

With the first ploughing soon after the harvest of the crops, tilth was determined by the field sieving method. The figures of this determination will be, however, considered later when discussing the seasonal changes in tilth.

TABLE I

Dates of sowing and harvesting and average yields in different kharif *rotational crops*

Treatment	Date of sowing	Date of harvest	Approximate period of growth	Yield per acre (lb.); averages of four replicate plots
Groundnut . .	16 June 1936	14 December 1936	6 months .	3,520 (dry pods)
Cotton . . .	3 May 1936 .	2 December 1936 (final packing)	7 ,, .	1,904 (seed cotton)
Jowar . . .	2 July 1936 .	16 October 1936	3½ ,, .	22,125 (green fodder)
Fallow . . .	21 May 1936 (first irrigation)	10 September 1936	3½ ,, .	10,673 (green weeds)
Sunn . . .	21 May 1936	18 August 1936	3 ,,	22,409 (green matter)
Patada shevra . .	21 May 1936	14 September 1936	3½ ,, .	14,976 (green matter)

Soil studies before cane planting

The main soil studies, which were done in great detail, were undertaken in January 1937, and may be classed in two categories : (*a*) soil tilth and properties expected to be closely associated with this condition and (*b*) fertility factors. Most of these were done in as large a number of replications as possible so as to allow of their being statistically worked out. The determinations and number of replicate observations for each are given in Table II. For the present discussion, however, only the average figures for the various properties and their bearing on the general soil condition and on the subsequent cane crop will be dealt with. The statistical part of the work will be published separately along with other replicated data of soil analyses.

TABLE II

Number of replicate observations taken for the different soil properties

	Number of observations per plot	Total number of observations for each treatment
(*a*) Soil tilth, etc.		
1. Single value index for tilth by field-sieving	20	80
2. Moisture	10	40
3. Nitrate	10	40
4. Oxygen-giving power	5	20
5. Dispersion coefficient	1	4
6. Bacterial number	..	1
(*b*) Fertility factors		
1. Nitrogen	1	4
2. Humus	1	4
3. Carbon	1	4

The average single-value figures for soil tilth, the dispersion coefficient and moisture are given in Table III.

It may be seen that the soil tilth is best after *patada shevra* followed more or less closely among themselves by the treatments *jowar*, cotton and groundnut, tilth after fallow and sunn being comparatively inferior. This latter result is rather unusual, the general expectation being that green manuring should have improved the condition of soil tilth. The only explanation that can be offered for this phenomenon is that the burying in of sunn (and weeds in fallow in the present case) has to be finished during breaks in the rains which keep the land more or less continuously wet during late August and in September. Consequently, it is likely that the soil structure might have been temporarily destroyed to a certain extent due to the slightly wet condition of the soil at the time of ploughing. But this was unavoidable. It is interesting to note that Russell and Keen [1938] have observed a similar difficulty of carrying out tillage operations at the proper time in their work on the effect of cultivation on crop yield. Dispersion coefficient, on the principle of lower dispersion indicating better tilth, shows somewhat the same trend, although not exactly in the same order, which in this case is cotton, *patada shevra*>*jowar*, groundnut>sunn>fallow. It thus shows a fairly good agreement with tilth by sieves. Moisture shows a certain amount of variation among

the treatments and is, except in groundnut, higher where tilth is inferior, e.g. in sunn and fallow. There are two aspects of the moisture content of the soil to be considered. One is, how various factors under the different crops have contributed towards the present moisture status of the soil. Second is, how this moisture condition has affected the separation of the natural aggregates by sieving which has been discussed below in connection with the relationship with tilth and other properties. With regard to the first aspect, making due allowances for other factors which may have been responsible for modification of soil moisture, there is perhaps yet some scope for the interpretation that the higher moisture content in treatments with inferior tilth (excepting groundnut) has been due to the holding up of the moisture in the upper layers on account of imperfect drainage caused by bad tilth.

TABLE III

Average single-value figures for tilth, dispersion coefficient and moisture in soil after different rotational treatments

Treatment	Single-value index for soil tilth	Dispersion coefficient	Moisture per cent
Groundnut	238±5·2	48·40	27·3±0·609
Cotton	243±5·0	31·05	24·8±0·667
Fodder *jowar*	253±7·1	46·93	21·2±0·785
Fallow	195±5·3	62·64	26·4±0·649
Sunn	184±4·9	52·20	28·1±0·552
Patada shevra	276±7·9	33·24	25·2±0·991

Average bactertial number, nitrate and oxygen-giving power are shown in Table IV.

Generally speaking, the green-manuring treatments in which fallow has been included are superior both in bacterial number and the nitrate content to the other treatments, the effect, if any, of the condition of soil tilth being completely masked by the effect of addition of green matter. Among the green manures, the green matter incorporated (Table I) has caused a proportionate increase in nitrate but not in bacterial number. The oxygen-giving power was expected to be more with better tilth and the figures, which are direct colorimetric readings with a standard 'aloin' solution, should be comparatively lower in the case of treatments with better tilth. There is, however, no consistency that can be seen in the data.

TABLE IV

Average bacterial number, nitrate and oxygen-giving power in soil after different rotational treatments

Treatment	Bacterial number	Nitrate (NO_3-N)	Oxygen-giving power*
	per gm. of dry soil	mg./100 gm. dry soil	
Groundnut	56,000	0·03 ± 0·0090	2·68 ± 0·1712
Cotton	23,750	0·02 ± 0·0054	3·56 ± 0·2159
Fodder *jowar*	32,000	0·02 ± 0·0046	3·10 ± 0·1688
Fallow	116,000	0·06 ± 0·0105	3·12 ± 0·2655
Sunn	67,500	0·29 ± 0·0480	3·34 ± 0·2135
Patada shevra	158,750	0·14 ± 0·0042	3·09 ± 0·2032

*Direct colorimetric readings with a fixed height of standard 'aloin' solution

The general relations between the tilth and other properties are well brought out in Fig. 1.

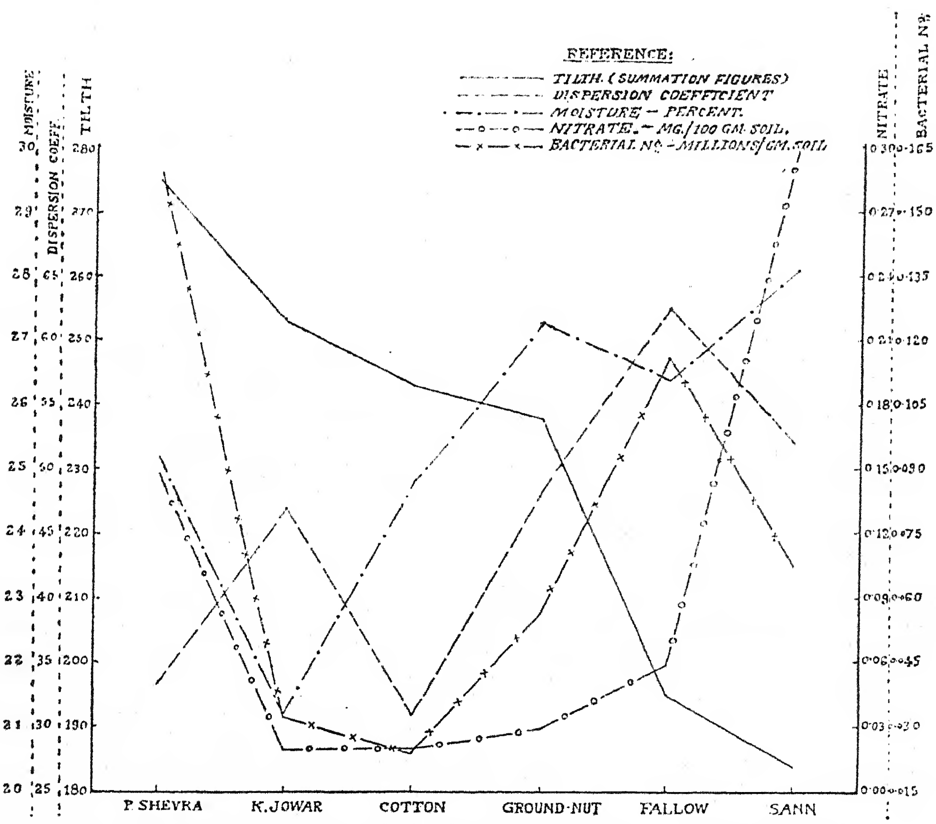


FIG. 1. Relationship between tilth and other associated soil properties

Here the tilth figures, arranged in descending order, have been joined by an entire line and the other corresponding properties (excepting oxygen-giving power) have been plotted and joined by various other distinguishing lines. It can be seen that the curve for dispersion coefficient runs more or less in the opposite direction to that of the tilth curve, thus showing the inverse relation between the two types of determination of the same soil property. The moisture curve shows for the greater part of its course a fairly good parallelism with the dispersion-coefficient curve, thus indicating the relation between the two. The nitrate and bacterial number curves are independent and form nearly parallel trough-like figures.

In considering the effects of the crops on the fertility factors, it was thought better to see to what extent the different treatments have modified the original level of these constituents rather than compare the figures only at the end of the experiment. In Table V nitrogen and humus contents of the soil, before and after the different treatments and their ratios with the original as 100, are given.

Table V

Average nitrogen and humus contents of soil before and after different rotational treatments

Treatment	Nitrogen (mg. per 100 gm. soil)			Humus (per cent)		
	Original	Final	Ratio with original as 100	Original	Final	Ratio with original as 100
Groundnut .	49·9	51·1	102·4	0·68	0·65	95·6
Cotton	50·7	53·8	106·1	0·72	0·69	95·8
Fodder *jowar* .	53·0	49·8	94·1	0·70	0·71	101·5
Fallow . . .	52·3	54·2	104·1	0·69	0·66	95·6
Sunn . . .	53·4	57·7	110·0	0·72	0·71	98·6
Patada shevra .	49·6	54·7	113·9	0·66	0·69	104·6

A general scrutiny of the figures shows that the nitrogen status of the soil has been appreciably raised by sunn and *patada shevra* to the extent of 10 and 13·9 per cent respectively. Fallow has been very successful as the increase of 4·1 per cent cannot be considered as appreciable. Among the other treatments, cotton tends to enhance the nitrogen level while *jowar* has slightly depressed it. Groundnut has caused very little change. Comparing the actual nitrogen content of the soil after the treatments (i.e. the nitrogen leve

which would be further directly useful for the succeeding cane crop) it may be observed that it is the highest in sunn followed with small variations among themselves by *patada shevra*, fallow and cotton. Groundnut and *jowar* are comparatively poor. An important point which would have to be considered in this connection is the ease with which this nitrogen in various treatments would mineralize and supply available nitrogen and there is an indication from the higher nitrate figure in the green manure treatments that the nitrogen in these plots is more readily available. With regard to humus there seems to be a general tendency for lowering of this constituent, even in the green-manuring treatments. It is not clear whether in these latter treatments, where considerable amounts of organic matter have been added, this is due to rapid oxidation and consequent loss of organic matter under tropical conditions.

As is well known, C/N ratio is an important factor in controlling the biological activities of the soil, and in fertility investigations on cane soils conducted at this station, it was found to be one of the main clues to the state of temporary soil exhaustion. It was, therefore, felt desirable to examine the C/N ratios of the soil as affected by the rotational treatments and how they were likely to affect the succeeding cane crop. In Table VI average figures for carbon and C/N ratios before and after the rotational treatments are given.

TABLE VI

Average carbon contents of soil and C/N ratios before and after different rotational treatments

Treatment	Carbon			C/N ratio		
	Original	Final	Final as percentage of original	Original	Final	Final as percentage of original
	per cent	per cent				
Groundnut	1·23	1·17	95·1	24·7	23·0	93·1
Cotton	1·21	1·24	102·5	23·9	23·0	96·2
Fodder *jowar*	1·23	1·19	96·7	23·3	23·9	102·5
Fallow	1·17	1·11	94·8	22·6	20·7	91·6
Sunn	1·15	1·09	94·8	21·5	18·9	87·9
Patada shevra	1·10	1·17	106·4	22·2	21·5	96·8

The carbon contents of the soil in all treatments except cotton and *patada shevra* are showing slight decreases from the original but the changes are generally not so pronounced for any definite conclusions to be drawn. However, the tendency for lowering in carbon in the treatments fallow and sunn

requires mentioning and is again an indication of rapid oxidation of the organic matter which was added much earlier in these cases than in *patada shevra*. This corroborates the observations on the humus content. With regard to the modification of the C/N ratios by the different treatments, it may be seen that fallow and sunn have appreciably lowered the ratio. This may be taken to be a favourable indication of their effects. The C/N ratio under *patada shevra* has shown only a slight decrease and it is likely that this is due to incomplete oxidation of the organic matter which was incorporated, as has been stated above, much later than in sunn and fallow.

It may be worthwhile, in passing, to mention about the actual values of the C/N ratios obtaining in these soils. This ratio is considered to be about 10 to 12 in normal fertile soils, in comparison with which the ratios reported here will seem to be too high. The question of a certain amount of variation in the ratio in different climatic regions has been discussed by Russell [1937] wherein he has quoted figures obtained by McLean for Transvaal black loam as 14·4. Recently, Hosking [1935], when comparing the properties of the Australian black earths with the *regur* of India has reported variations between 13·5 to 18·5 for Australian soils and 8·3 to 21·3 for *regur*. Further corroboration is available for high ratios in the latter soils from the work of Sahasrabuddhe [1929], from whose figures for carbon and nitrogen for a typical black soil in the Poona district, the C/N ratio on calculation is found to give a figure of 23·0.

Effects of different rotational treatments

The effects of the general soil conditions, particularly of tilth, left after the various rotational treatments were closely observed on a crop of cane, planted soon after the completion of the studies described above. The choice of a suitable variety for this experiment presented a matter for some thought. It was felt that it would be desirable to have a variety which would withstand the effects of vagaries of the climate and thus be sure of completing a successful growth period, but which at the same time would fairly reflect in its growth and behaviour the effects of the treatments. From these points of view the choice fell on Co 419 which had also the advantage that it was being generally adopted in the canal areas and, therefore, it was believed that the results of this experiment would possess a fairly wide applicability.

The cane was grown according to the standard method of cultivation which was recommended at that time by the station, the main features being a 4 ft. spacing between rows, 10,000 setts (of three eye-buds each) per acre, and 150 lb. nitrogenous top-dressing half as S/A and half as cake, given in three equal doses of nitrogen at three and eight weeks after planting and finally at earthing up, about 4½ to 5 months after planting. No basal dose of manure was given to any of the treatments. It is of course usual that where the land has been green manured, no basal dose of manure is applied, but in the present experiment it was purposely withheld even in the other treatments in order to avoid the interference of the treatment effect by the manure.

The rapidity of germination of cane was the first observation to be taken as a factor most readily susceptible to the condition of soil tilth. The results are shown in Table VII where the treatments have been arranged in

descending order of their tilth and the corresponding germination at three and eight weeks respectively after planting shown against them.

TABLE VII

Germination of cane after different rotational treatments

Treatment	Tilth before cane planting (single value index)	Germination (per cent)	
		Three weeks after planting	Eight weeks after planting
Patada shevra	276	48·0±1·343	71·0±1·378
Fodder *jowar*	253	48·7±1·475	69·8±1·396
Cotton	243	46·1±1·691	72·0±1·138
Groundnut	238	46·1±1·425	70·7±1·096
Fallow	195	46·1±1·911	73·1±1·143
Sunn	184	36·9±1·424	69·5±1·160

It may be observed from Table VII that the trend of the germination at three weeks is a fair reflection of the tilth. For, leaving aside the figures for *jowar* and fallow, *patada shevra* has given the highest germination, followed by cotton and groundnut, where evidently minor differences in soil tilth have not caused any outstanding differences in germination. The striking result is the poor germination in sunn which had comparatively inferior tilth. It must be, however, explained here that ordinarily a simple interpretation of this kind of the germination of cane is beset with difficulties due to unevenness of planting but special precautions such as proper selection of seed material etc. were taken to ensure that the conditions of planting were made as uniform as possible [Rege and Wagle, 1939]. The germination at the end of eight weeks has, however, nearly equalized in all cases showing that the tilth condition was only effective in promoting a quicker initial germination. Russell and Mehta [1938] found similar results when studying the effect of seed-beds produced by different cultivation implements on the germination of wheat. They observe : 'The germination on the roto-tilled plots was more rapid than on the other treatments studied for the first few days. Then the other treatments usually catch up, and when germination is complete there is no systematic difference in favour of any treatment.'

During this time when the cane was germinating the growth and vigour of the seedlings was closely watched and from the time when the cane had fairly established itself in all the treatments it was apparent even from visual examination that the seedlings in treatments which had better tilth were more vigorous and showed a better stand than in treatments which had inferior previous tilth. Quantitative determinations based on the weights of the seedlings were then started from a period of ten weeks after planting.

These latter observations on the growth of cane consisted of taking the weights of plants cut from a 2 ft. length of row from each plot at certain important stages of the crop growth. These strips were selected to represent the average growth of plants over the whole plot and, after exposing the setts by removal of the overlying soil, the plants were cut and immediately sent to the laboratory where they were weighed and a representative sample kept for moisture. The roots of the plants were separated, washed thoroughly to remove adhering soil, dried and weighed.

The shoot weights and root weights at different periods are shown in Table VIII.

It will be seen from the figures that, in the first period the shoot weight is highest in cotton, next in *patada shevra*, followed in somewhat close order by the other treatments. In *jowar*, the shoot weight is lowest among the treatments, and it may also be observed that sunn and fallow are much poorer than either cotton or *patada shevra*. In the second period of study, viz. 14 weeks after planting, cotton still retains its superiority but the margin is now narrower, the other treatments having made some headway. *Jowar*, however, continues to be the poorest among the treatments. A notable feature of the third period of study, which was taken first before earthing up is the progress made by sunn which is now highest in shoot weight and has even surpassed cotton. Fallow, however, has not made similar progress, while groundnut and *jowar* are now comparatively inferior among the treatments.

TABLE VIII

Periodical weights of shoots and roots in cane after different rotational treatments

(Dry matter in gm. in 2 ft. row lengths)

(Average of four observations per treatment)

Treatment	10 weeks after planting (16 April 1937)		14 weeks after planting (17 May 1937)		20 weeks after planting (26 June 1937)	
	Shoot weight	Root weight	Shoot weight	Root weight	Shoot weight	Root weight
Groundnut .	57·8	11·4	198·0	26·7	673·7	82·5
Cotton . .	89·2	15·9	262·3	36·8	823·9	110·3
Fodder *jowar* .	50·8	13·3	177·3	26·8	670·6	91·1
Fallow . .	55·3	12·3	233·7	32·6	698·5	91·8
Sunn . .	60·0	11·7	195·4	28·0	848·2	119·3
Patada shevra .	74·0	12·7	217·2	25·5	785·1	109·2

Regarding the weights of roots, at the first period, the weight is highest in cotton, and then in descending order, with small differences among themselves, being *jowar*, *patada shevra* and fallow. Sunn and groundnut are inferior. In the second period, cotton is still best with fallow, which has since moved up, a close second. The other treatments are more or less alike. In the third stage there is highest root development in sunn, followed by cotton and *patada shevra* which are nearly equal, the other treatments, particularly groundnut, being inferior.

Considering the relation which these two factors bear with the soil conditions, it may be stated that in the first stage the greater weights of both shoots and roots have been associated with the previous better tilth shown by the treatments, though not exactly in the same order. Cotton and *patada shevra* are especially prominent in this respect in both shoot and root weight while the condition under *jowar* has reflected only in a better root weight. This is probably the period when the physical condition of soil has a more pronounced effect on the plant growth under the present conditions of study. In the second stage we find that the green-manuring treatments which had the advantage of a higher level of fertility gradually making up and from this time onwards the effect of the soil tilth is masked by fertility factors. Of particular interest are the effects of cotton, which has encouraged cane growth much beyond what was expected from its condition of tilth and fertility, and in the third period of study, although sunn has surpassed it in total growth, it still remains superior to *patada shevra* and fallow. This order was more or less maintained in further growth observations like height, girth, etc. and in the final yield of cane.

The determination of soil tilth at periods corresponding to the above growth observations was attended with difficulties. The soil, even nine days after irrigation (i.e. just before the due date of the next irrigation) is usually too wet for the field-sieving method to be successfully employed. No other kind of any special apparatus, e.g. Tiulin's sieves for measuring the water-stable crumbs, was available. This has been adopted in our later studies. Other methods, more or less improvized or only just indicative of the general state of things, had to be adopted. During the first stage the distribution of irrigational water in the profile in 6 in. layers to a total depth of 2 ft. was determined on the assumption that a free and easy penetration would indicate a better physical condition or tilth of the soil. These results did not fulfil expectations and the most which could be said about them is that among the treatments only *patada shevra* and cotton showed a gradual gradient of moisture from the top to the lower layers and could thus be said to have retained their former good tilth.

At two subsequent periods the dispersion coefficient which was also done before cane planting and has already been described, was employed as an indication of soil structure. The results are shown in Table IX.

The attainment of a nearly uniform state of micro-structure even from the second period of our study (i.e. 14 weeks after planting) is shown by the first set of figures. The values at the later period (20 weeks) are also nearly equal but the general dispersion is slightly higher than at the former period,

TABLE IX

Dispersion coefficient of soil at various periods of growth of cane after different rotational treatments

(Averages of four separate determinations)

Treatment	At 14 weeks after planting	At 20 weeks after planting
Groundnut	59·78	62·42
Cotton	58·13	59·10
Fodder *jowar*	58·24	61·09
Fallow	59·38	62·74
Sunn	58·56	61·55
Patada shevra	58·47	64·46

These studies would appear to indicate that the soil structure under irrigation and cane growing tends to equalize whatever the previous treatment.

The ultimate effects of the different rotational treatments on the cane crop may be seen on the final yield of cane the figures for which, with other observations, are given in Table X.

TABLE X

Harvest data of cane after different rotational treatments

(Averages of four replicate plots)

Treatment	Yield per acre		Calculated weight per cane in lb.	Purity of juice per cent
	Number of canes	Weight in tons*		
Groundnut	26,917	24·32	2·02	92·0
Cotton	30,782	28·85	2·10	89·3
Fodder *jowar*	28,083	26·76	2·13	91·5
Fallow	30,080	30·39	2·26	91·8
Sunn	32,873	32·68	2·23	90·7
Patada shevra	33,159	34·27	2·31	92·1

* Critical difference for significance 4·29 tons per acre

It is evident from the figures given in Table X that the yields of treatments fall into two groups, green-manuring and otherwise, the green-manuring treatments having finally established themselves as superior to the other treatments. In other words, the factors contributing to the fertility level of the soil have more than recompensed for the initial advantage obtained by some treatments due to superior tilth. Where both these factors were combined the yield has been the highest as in *patada shevra*. The order of yields is *patada shevra*>sunn>fallow>cotton>*jowar*>groundnut. The analysis of variance showed high significance for treatments. The critical difference for significance being 4·29 tons per acre, *patada shevra* is significantly superior to all except sunn and fallow (being very nearly so over the latter). Among the rotational crops, cotton stands out prominent as having had the best effect on the cane crop and is inferior statistically only to *patada shevra*. The order of yields generally agrees with that of the plant population and the weight per cane. It is of particular interest to note that in spite of higher number of canes in the green-manuring treatments in general, the weight per cane is also higher, showing the beneficial effects of higher available nitrogen (Table IV). The purity of juice, however, has not suffered on this account.

In summing up, it may be seen that the yields are well correlated with the initial nitrogen status of the soil. Referring back to Table V, it will be seen that in *patada shevra*, sunn, fallow and cotton which gave higher yields, both the actual nitrogen level as well as the extent of increase of the original by the treatment are higher, though not in the same order as of the yields. Conversely, in the treatments groundnut and *jowar*, it can be said that the nitrogen deficiency caused by them has been the main factor in depressing the cane yield. It was also pointed out that nitrate (Table IV) was higher in the green-manuring treatments indicating a higher level of available nitrogen before cane planting. It is likely that in these treatments the ready supply of available nitrogen continued during the life of the cane crop. With regard to other factors that may have induced better growth in the green-manuring treatments, the tendency to lower the C/N ratio (Table VI) is likely to have had a beneficial effect on the biological activities in soil favourable to plant growth. The available phosphoric acid was also determined before and after some of the rotational treatments in the expectation that this would throw some light on the behaviour of cane yields but the figures did not show any consistency.

Soil condition after completion of one rotational cycle

After the harvest of the cane crop soil tilth was again determined to see the condition left after the completion of the rotational cycle. Field-sieving was done as before but as it was thought that the cane roots which are fairly extensive might interfere with the sieving, the tilth was separately determined within the root zone and away from it, the figures for which and those for the corresponding moisture contents are shown in Table XI.

It will be observed that in spite of differences in moisture content the tilth figures are fairly close. It is likely that the whole of the soil mass must have been reduced to the same condition of tilth by cane growing and later the soil away from the root zone, i.e. near the surface and in the intervening

TABLE XI

Comparative figures for soil tilth and corresponding moisture contents after cane within and without the root zone

(Averages of 40 separate determinations per treatment)

Treatment previous to cane	Within the root zone		Without the root zone	
	Single-value index for tilth	Moisture (per cent)	Single-value index for tilth	Moisture (per cent)
Groundnut	222	21·7	207	16·0
Cotton	229	20·6	232	15·4
Fodder *jowar* . . .	242	19·3	258	17·2
Fallow	212	20·8	217	14·9
Sunn	206	21·2	217	16·3
Patada shevra	227	21·3	226	16·4

spaces between the cane rows must have dried to a lower moisture content. It is noteworthy that, though the soil had attained the same state of micro-structure as shown by the dispersion coefficient during cane growth, the trend of the present figures is not very dissimilar from that before cane planting. That is, treatments *jowar*, cotton and *patada shevra* are in a group showing more or less better tilth while fallow and sunn are still inferior from this point of view. Either the treatment of agitation that the soil undergoes during the determination of dispersion coefficient is so drastic as to reduce the soil to the same micro-structure or, the soil, after partial drying, has taken up a field alignment of soil particles similar to that before cane planting. This aspect will be probably clarified when the determination of water-stable crumbs which are in progress at present is completed. At the same time it may be noted that the differences between the various treatments tend to narrow down after cane growing. Another remarkable result is that, after the drastic treatment, particularly by way of frequent heavy irrigations, the soil has undergone during cane growing, the tilth has remained at a comparatively high figure in all the treatments, having actually increased in fallow and sunn.

Changes in the micro-structure due to cane growing

While considering these changes in the summation figures (single-value indices) for soil tilth from time to time it would be worthwhile to go into the details of the changes which the various fractions have undergone. Accordingly, the average summation figures for tilth immediately after the harvest

of the *kharif* crops in 1936, those just before cane planting in January 1937 and, finally after the harvest of cane in March 1938, with the proportions of the different soil aggregates on each occasion are given in Table XII.

TABLE XII

Results of aggregate analysis of the soil, after harvest of kharif *crops, before cane planting, and after harvest of cane*

(Averages of 80 separate determinations per treatment)

Treatment	First fraction > 1½ in.	Second fraction >5/8 in.	Third fraction > 1/4 in.	Fourth fraction >3 mm.	Fifth fraction > 3 mm.	Average summation figure	Critical difference for significance (P= ·05)
	Percentages of total weight of soil						
Groundnut—							
a . . .	51 ·9	17 ·5	12 ·0	12 ·7	4 ·6	235	
b . . .	63 ·3	15 ·7	7 ·2	7 ·0	6 ·7	238	14 ·4
c . . .	59 ·1	21 ·0	8 ·0	6 ·5	5 ·4	207	
Cotton—							
a . . .	64 ·0	13 ·8	8 ·1	8 ·7	5 ·2	217	
b . . .	63 ·3	16 ·4	6 ·9	6 ·4	7 ·0	243	13 ·9
c . . .	54 ·1	24 ·0	8 ·7	7 ·1	5 ·9	232	
Fodder *jowar*—							
a . . .	66 ·8	13 ·0	7 ·2	6 ·8	6 ·1	223	
b . . .	64 ·2	15 ·4	6 ·4	6 ·2	7 ·8	253	19 ·6
c . . .	51 ·2	23 ·9	9 ·2	8 ·1	7 ·0	258	
Fallow—							
a . . .	62 ·6	13 ·0	9 ·1	9 ·5	5 ·1	221	
b . . .	68 ·0	15 ·3	6 ·3	5 ·5	5 ·0	195	14 ·6
c . . .	54 ·8	24 ·5	8 ·6	6 ·6	5 ·4	217	
Sunn—							
a . . .	67 ·9	13 ·3	7 ·7	7 ·1	3 ·9	183	
b . . .	70 ·3	14 ·0	5 ·9	5 ·2	4 ·6	184	13 ·2
c . . .	57 ·8	21 ·2	8 ·6	6 ·6	5 ·5	217	
Patada shevra—							
a . . .	60 ·4	12 ·3	8 ·7	10 ·5	7 ·9	280	
b . . .	58 ·7	16 ·9	7 ·6	7 ·7	9 ·1	276	21 ·8
c . . .	55 ·3	22 ·0	8 ·8	7 ·2	5 ·8	226	

a=after harvest of *kharif* crops
b=before planting of cane
c=after harvest of cane

Considering the figures against '*a*' in Table XII, i.e. soon after harvest of the *kharif* crops, it can be seen that the order of tilth, according to summation figures, is *patada shevra*>groundnut>*jowar*, fallow, cotton>sunn. Regarding the proportion of different-sized aggregates in the different treatments, it may be observed that the fraction larger than $1\frac{1}{2}$ in. (i.e. the fraction remaining on the first sieve) forms by far the largest portion. The differences in the final tilth figures appear to be due mainly to variations in the first and the last fractions. It may be remembered that, as the last fraction has to be multiplied by 20 to obtain its relative surface area even a small change in this fraction is liable to cause an appreciable variation in the summation figure. In *patada shevra* there is the highest proportion of the last fraction among the treatments and in sunn there is the lowest proportion of this fraction accompanied by the highest proportion of the first fraction.

The condition of tilth in January 1937 after the soil in these treatments has been left to the weathering action of the atmosphere, as well as that due to green manuring in those treatments (figures against '*b*' in the table) shows some interesting changes. Taking the summation figures, cotton and *jowar* show some improvement, fallow shows a slight decrease, there being no appreciable change in the other treatments. Regarding changes in individual fractions there is a general trend of comminution of the fourth fraction (indicated by decreases in this fraction) giving rise to an increase in the last fraction. This is, however, offset by an opposite tendency of the smaller particles to coalesce and form larger particles as shown by decrease of these particles (third and fourth) and an increase of larger particles (second). This movement in some cases extends up to the first fraction ($1\frac{1}{2}$ in.). The increase or decrease of the summation figure is determined by the extent of this counterbalancing.

The single-value figures for tilth, determined after the harvest of cane (figures against '*c*' in the table) show, as has been pointed out, a considerably smaller variation among the treatments than that prevailing before planting. The tilth in *patada shevra* and groundnut has shown decrease (also cotton to a slight extent) whereas fallow and sunn show some improvement. The changes in the fractions during the cane cropping are chiefly characterized by a very interesting trend, viz. that with the exception of fallow and sunn, the three central fractions tend to be built up by movements from both directions, by comminution of the largest fraction as well as the coalescence of the smallest. And as before, the summation figure depends on the extent of these two movements. In fallow and sunn the movement has been largely in one direction, that of comminution of the larger particles into the smaller, which has resulted in an increase of the summation figure. On the whole, the changes in the structure that are apparent under one cane crop are very encouraging in that they not only do not indicate any deterioration of tilth but, on the contrary, actually show a building up certain group of particles. Possibly this is due to the effect of the root system of the cane crop which, while it helps to break up larger clods by its extensive ramifications, also at the same time helps the formation of granules along its finer roots.

Summary and conclusions

This paper deals with investigations regarding the effects of certain common *kharif* rotational crops and green-manure treatments on the soil and on a succeeding cane crop. The *kharif* treatments were : (1) cotton, (2) groundnut, (3) fodder *jowar*, (4) sunn-hemp, (5) *patada shevra* (a selected leguminous weed) and (6) fallow. The experiment was laid out on the randomized block method with four replicates on a typical black cotton soil at the Padegaon farm, and the main conclusions reached during this investigation are as follows :—

From a detailed soil examination done after disposal of the crops, soil tilth as measured by Keen's method of sieves showed the descending order of treatments, *patada shevra* > *jowar* > cotton > groundnut > fallow > sunn. Among properties examined which were likely to be related to tilth, the dispersion coefficient of soil showed a fair agreement, having an inverse relationship with tilth. Moisture showed good parallelism to the dispersion coefficient within a certain limit. The nitrate and bacterial number, however, did not show any relation with the tilth condition and were generally much higher in the green-manuring treatments (including fallow where weeds were buried in). Oxygen-giving power did not give consistent values. Among fertility factors nitrogen status was found to have been appreciably raised by *patada shevra* and sunn and to a small extent by cotton and fallow. No definite trend was noticeable in the humus contents, but the green-manuring treatments showed a tendency to lower the C/N ratios of the soil.

With regard to the effect of the rotational crops on the succeeding cane, it was found that the treatments with the better initial tilth induced a quicker germination although at the end the germination equalized under all treatments. The effects of tilth were also reflected to a certain extent in the weights of shoots and roots of cane up to a period of about 10 weeks after planting. After this period other factors slowly dominated, and the green manure treatments ultimately established themselves superior to others.

Soil examination, done at the same periods when the growth observations were taken, showed that the dispersion coefficient was almost equal for all treatments from the period of 14 weeks after planting, indicating the attainment of an equal value for soil structure in all treatments.

The final yields of cane were definitely associated with better fertility, being in the order of *patada shevra* > sunn > fallow > cotton > *jowar* > groundnut. Statistical analysis showed high significance for treatments and that *patada shevra* was significantly superior over all the treatments except sunn and fallow (nearly so over the latter). The yield after cotton was very promising as it was highest among the rotational crops and only *patada shevra* was significantly superior to it. *Jowar* and groundnut proved to be much inferior to cotton under these conditions.

Finally, quantitative studies on soil tilth indicate that cane growing actually improves the field soil structure by building up certain desirable groups of soil aggregates. It is suggested that the beneficial effect of cane growing on the soil tilth may be due to the extensive root system of sugarcane.

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PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN CANAL TRACT

IV. MINERAL NUTRITION : (A) PHOSPHATES

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Introduction

In the Deccan canal tract, sugarcane is an irrigated crop and is manured heavily with nitrogenous top-dressings consisting mainly of sulphate of ammonia and safflower, groundnut or castor-cakes. The soils, being deficient in nitrogen, the crop invariably responds to these manures quite perceptibly and consequently the cultivation of sugarcane involves a large expenditure on these nitrogenous manures alone. In any investigation in the mineral nutrition of sugarcane, therefore, nitrogen stands pre-eminent requiring the first attention and we have accordingly concentrated our researches on this element the results of which will be described in a separate paper.

In any systematic studies on the optimum absorption of individual element by the plant, it would be necessary to have for comparison a plant of the same species under conditions of balanced nutrition. While the experimental evidence from the various workers in this field is rather conflicting, making it impossible to put forth any definite generalizations, it is apparent that there exists for each plant species a physiologically balanced nutrient solution from which normal absorption occurs, resulting in the greatest growth and yield. A departure from this balance, either through deficiency or excess of any one element will produce a disturbance in the absorption of different elements which may exert profound effects on metabolism. The researches in the nutrition of any one element by the plant would thus require the initial determination of the availability of other elements in the soil in order to prevent any unbalanced nutrient supply to the plant and as the main aim of our investigation was to determine the nitrogen nutriment of sugarcane, it was considered quite essential to initially test the soil under experimentation for the availablity of the other two important manurial constituents, viz. phosphate and potash.

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The soils of the Deccan canal tract belong to the broad group of *regur* or black cotton soil, which is further recently classified into distinct soil types according to the genetic system of soil classification by Basu and Sirur [1938]. Two of these soil types, viz. B and F are existent on the farm, the major area being under the former type. The type F is very shallow, the average depth being about 15 in., while the other type possesses a depth varying from 3 ft. to 12 ft. For the individual characteristics of these types, the original paper referred to above may be consulted. The chemical analysis of these soil types for both the total and available phosphate and potash could not, however, be properly interpreted as regards the deficiency or otherwise of these minerals owing to the absence of any further information about their limiting figures for sugarcane in these types as is now collected, for instance, for the Hawaiian soils. In order to get immediately a definite idea about the state of these constituents in the soil under experimentation, it was, therefore, considered advisable to study the effect of the application of potassic and phosphatic fertilizers on the cane growth directly in the field.

Outline of the scheme of work

At the outset, a small-scale experiment with duplicate plots only was laid out during the season of 1933-34 with both the potassic and phosphatic fertilizers in the soil type B which was selected for the detailed studies in the nitrogen nutrition of sugarcane.. A top-dressing of 150 lb. N in equal proportions of sulphate of ammonia and safflower-cake as recommended in the standard Manjri method [Bombay Dept. of Agric., Leaflet No. 17 of 1929] was common to all the three treatments. One of these treatments received in addition 100 lb. P_2O_5 in the form of superphosphate and the other 100 lb. K_2O in the form of sulphate of potash as basal manuring, the third treatment being the control receiving no basal manuring. The results are given in Table I.

TABLE I

Comparative studies in the effect of phosphatic and potassic treatments

(Variety Pundia; Date of planting 17 January 1933; Date of harvest 11 January 1934)

Treatment	Germination at eight weeks (per cent)	Number of canes per acre	Calculated yield per acre in tons	Weight per cane	Brix on 26 September 1933	Brix on 11 January 1934
Control—150 lb. N alone	57·9	28133	34·8	2·77	11·9	16·0
150 lb. N + 100 lb. P_2O_5	63·9	33578	43·7	2·85	12·2	16·9
150 lb. N + 100 lb. K_2O	62·3	29040	36·3	2·80	11·5	16·2

These results clearly reveal the deficiency of phosphate in the soil. Its effect seems to be mainly on the number of canes. The weight per cane is practically similar in all the treatments and the higher tonnage obtained in the one receiving phosphatic manuring is, therefore, mainly due to the presence of a large number of canes at the harvest time. The figures for brix also indicate

a tendency towards the early attainment of maturity in this treatment. On the other hand, there has been practically no variation from the control in the behaviour of the crop with potassic manuring which clearly suggests the sufficiency of the potash in the soil. Any further investigation in the potassic manuring was, therefore, stopped, while the finding about the beneficial effect of the phosphatic manuring was critically tested in a large scale replicated experiment with the same sugarcane variety and under the same nitrogenous treatment by the agricultural section for two consecutive seasons of 1934-35 and 1935-36. During the first season, the phosphatic treatment gave 43 per cent higher tonnage showing a very high significance. The results were not so very outstanding during the second season, mainly due to the unfavourable climatic conditions during the grand period of growth. In spite of this, this treatment gave 15 per cent higher yields which just approached the statistical significance. Similar trial by the Soil Physicist in the soil type F with POJ 2878 and with a higher nitrogenous dose of 300 lb. N applied only in the form of sulphate of ammonia gave almost double the yield in the case of the phosphatic treatment. These statistical trials have thus confirmed the preliminary observation about the phosphatic deficiency in the soil under investigation and as a result, the application of a basal dose of 100 lb. P_2O_5 was introduced in all our major field trials in the nitrogen nutrition of sugarcane.

As the necessity of phosphatic manuring was definitely established, the next course was to determine the suitable times of its application both from the standpoint of its action on the plant development and maturity, and also the period for which the effect of superphosphate once applied continued. Besides the developmental studies, this naturally required detailed investigations in the uptake of nutrients by periodical sampling, and, therefore, a special experiment was laid out for the purpose during the season of 1937-38 and was also repeated in the next year. During the first season, the block selected for the experiment had received no phosphatic manuring any time previously, while the next year's experiment was shifted to a similar block which had received the phosphatic application for the previous crop of sugarcane during the season of 1935-36, the underlying idea being to see whether the effect of the previous application of 100 lb. P_2O_5 in the form of superphosphate continued even in the fourth year of cropping. The rotation followed in these blocks was sunn, sugarcane and cotton, the first being ploughed in August for the next crop of sugarcane. POJ 2878 was selected as the sugarcane variety as it occupied the major area under the canal tract.

The manurial treatments consisted of (1) a top-dressing of 300 lb. N with and without an initial application of 100 lb. P_2O_5 in the form of double superphosphate and (2) top-dressings of 450 and 600 lb. N with and without 50 lb. P_2O_5 at earthing in addition to the initial dose of superphosphate at the rate of 100 lb. P_2O_5 common to all. The first series was intended to determine the effect of phosphate on the plant development and the second its influence on maturity which was found to be greatly delayed in the case of heavy nitrogenous manuring. These treatments were slightly modified during the next season by eliminating the one of 600 lb. N as this dosage was found to be far in excess of the crop requirement without any advantage in the production of cane and

instead, substituting the one of 100 lb. P_2O_5 without any nitrogenous top-dressing. In order to prevent the high concentration of nitrogen in the soil solution with such heavy top-dressings, the proportion of sulphate of ammonia to cake was kept to 1 : 2 with four times of application during both the years instead of 1 : 1 with three times of application as recommended in the standard Manjri method. There were duplicate plots for each treatment, the plot size being 28 ft. × 38 ft. with seven rows 4 ft. apart.

Presentation of the data

Developmental studies

Germination. Planting was done by mid-January in both the years at the rate of 10,000 three-budded setts per acre. Before planting, double superphosphate was added at the rate of 100 lb. P_2O_5 per acre with one-tenth of the total dose of nitrogenous top-dressing in the form of sulphate of ammonia only to all the phosphatic treatments except the no-nitrogen one which did not receive any nitrogen. The control treatment received only sulphate of ammonia. The results (Table II) clearly reveal that from the standpoint of germination, there is practically no advantage from the phosphatic manuring. On the other hand, there is an indication of the slight lowering in the rate of germination due to phosphatic manuring during both the seasons although the effect is not significant. In the case of the treatment P, however, there is a significant fall in the rate up to three weeks which clearly brings out the influence of nitrogen. Later on the differences between the treatments are greatly narrowed down. The acceleration of the germinative activity with the application of sulphate of ammonia at planting has already been described by Rege and Wagle [1939]. During the season of 1938-39, counts were not taken at eight weeks as tillering had already started after six weeks.

Table II

Periodical data of germination

(Per cent of the total buds planted)

(Variety POJ 2878; Average of all rows per plot excluding the end rows)

Treatment*	1937-38			1938-39	
	Three weeks counts	Six weeks counts	Eight weeks counts	Three weeks counts	Six weeks counts
(1) N—Control—N 300 lb. N only	36·9±2·25	78·7±1·23	78·7±1·17	45·5±2·51	83·5±1·38
(2) NP—300 lb. N + 100 lb. P_2O_5	33·9±1·75	74·4±1·1	78·3±1·49	42·1±0·76	82·3±1·49
(3) P—No nitrogen + 100 lb. P_2O_5	...	...	...	36·3±1·3	77·5±0·99

*As the effect of nitrogen will be discussed in a separate paper the data are not given for the other nitrogenous treatments

Tillering. After the completion of the germination, periodical counts of the total number of plants per row were maintained for two randomly selected rows per plot till the operation of earthing. The results are given in Table III after reducing the figures to 1 ft. length for convenience.

These observations could not be continued till harvest time owing to the periodical cutting of the plants for the uptake of nutrients, exudation, maturity tests, etc. In order to find out, therefore, the performance of the individual germinated bud throughout its life-cycle, 10 randomly selected mother plants per treatment were labelled for all the tillers formed from the beginning and their development was carefully noted monthly till harvest time (Table IV).

TABLE III

Plant population per foot and per cent borer attack

(Average of two rows per plot)

Date of observation	1937-38				1938-39					
	300 N+No P_2O_5 N		300 N+100 P_2O_5 NP		300 N+No P_2O_5 N		300 N+100 P_2O_5 NP		No N+100 P_2O_5 P	
	Plant population	Per cent borer attack	Plant population	Per cent borer attack	Plant population	Per cent borer attack	Plant population	Per cent borer attack	Plant population	Per cent borer attack
18 March	2·2	...	2·3	...	5·7	0·23	5·2	0·0	4·4	1·04
4 April	4·2	2·3	6·2	1·3	5·9	0·89	6·2	1·6	6·5	1·80
19 April	5·4	2·3	7·2	1·9	7·4	6·10	7·2	3·9	7·4	5·20
5 May	6·4± 0·24	4·6	8·4± 1·54	1·9	7·2± 0·84	5·70	7·8± 1·36	5·7	7·4± 0·54	9·10
5 June	5·7	5·0	7·1	3·5	5·1	8·60	5·3	10·3	5·1	8·10
21 June	4·9	...	6·5	...	3·8	10·80	3·3	12·5	3·2	8·10

TABLE IV

Plant population in 10 random stools

Date of observation	1937-38		1938-39		
	300 N + No P_2O_5 N	300 N + 100 P_2O_5 NP	300 N + No P_2O_5 N	300 N + 100 P_2O_5 NP	No N + 100 P_2O_5 P
18 March (mother canes)	10	10	10	10	10
16 April	30·0±2·05	42·0±2·5	28·0±5·4	28·0±4·15	41·0±3·8
16 May	33·0	34·0	26·0	27·0	32·0
18 June	27·7±2·7	31·0±1·9	24·0±2·7	19·0±3·3	24·0±2·2
16 July	19·0	26·0	20·0	17·0	19·0
15 August	18·0	26·0	20·0	17·0	19·0
16 September	18·0	26·0	19·0	17·0	19·0
17 October	18·0	26·0	19·0	17·0	17·0
15 November	16·0	26·0	19·0	17·0	15·0
15 December	1 6·0±2·6	26·0±2·05	19·0±2·6	17·0±2·46	14·0±2·4
15 January	17·0	26·0	19·0	17·0	...
Per cent successful plants	48·8	61·7	54·3	60·7	34·1

The comparison of the figures of the plant population for the season of 1937-38 reveals a higher tillering activity in the phosphatic-treated plots. There is also an early start in tillering which eventually leads to the higher success at harvest time (Table IV) as the early-formed tillers are generally found to escape the borer attack to a much greater extent. Similar results of increased tillering by phosphatic manuring have also been obtained by Brenchley [1929] in her water-culture experiments with barley. This effect is not, however, evident during the next season of 1938-39. Only in the case of treatment P there is some indication of increased tillering when the individual stools are considered (Table IV). Owing to the deficiency of nitrogen, however, a great majority of the tillers so formed suffered death greatly lowering the percentage success in the end.

Borer. The ravages of the stem borer were determined in the same rows selected for tillering counts by cutting the borer-affected plants at the time of tillering counts and counting their number. The data are given in Table III as percentage of the total population along with that of plant population. The less intensity of borer attack as a result of phosphatic manuring is quite apparent, the more so during the season of 1937-38 than in 1938-39. The reason for this variation is explicit in the previous treatments of the block already referred to. Further comparative studies of the figures for the two years indicate that on the whole its ravages are more severe during 1938-39 than in the previous one. This would be an important contributory factor in the lowering of the number of canes and tonnage per acre which are observed during the latter year (Table VI).

Growth. This has been periodically measured by two methods. In the first case complete botanical observations such as total height, height of millable cane, number of mature and immature internodes and circumference were taken monthly beginning from the third month after planting on all the plants in the 10 stools labelled for tillering. The methods are the same as already described by Rege and Wagle [1939]. These data are averaged per plant and are given in Table V. In the second method, the crop was harvested periodically at definite stages in growth and fresh weights of stems and green leaves were determined separately. For this purpose, two end rows and 4 ft. on either side of the intermediate rows were excluded from sampling in order to avoid the border effect. The remaining lengths of the rows were then divided into 3 ft. strips from which only alternate strips were earmarked for sampling by random selection. By this method there was no possibility of any of the selected strips abutting on the previously sampled ones. As sampling error was found to be very high during early stages, eight strips were utilized for sampling at these periods, the number being reduced to six later on. These data are given in Table VI.

It would be evident from the inspection of both these tables that during the season of 1937-38 when phosphate was applied for the first time, its beneficial effect was not restricted to the tillering phase alone but was even visible during the greater part of the growth phase. For instance, both in the case of total height and the height of millable cane, the advantage of the basal dose of phosphate (Table V, series I) was quite pronounced till mid-August and it was only after this period that the treatment of nitrogen alone had shown an

Table V

Periodical botanical data per plant

(Average of 10 random stools)

Date of observation	1937-38						1938-39								
	Total height in inches		Height of millable cane in inches		Ratio of millable to non-millable cane height		Total height in inches			Height of millable cane in inches			Ratio of millable to non-millable cane height		
	N	NP	N	NP	N	NP	N	NP	P	N	NP	P	N	NP	P
Series I															
17 April	6·7± 0·6	8·3± 0·34	...	...	...	...	8·3± 0·4	8·5± 0·7	7·4± 0·4	...	...	...	...	...	...
16 May	12·2	15·3	...	...	...	...	16·7	16·4	14·2	...	...	...	...	...	...
20 June	26·6± 1·8	36·1± 3·07	...	...	...	...	39·9± 2·7	38·3± 2·2	26·8± 2·3	...	...	...	...	...	...
17 July	34·5	46·6	...	...	...	...	55·3	54·6	30·6	...	...	...	...	...	...
16 August	59·4± 1·3	67·1± 1·99	47·5	57·5	0·25	0·17	74·5± 1·9	78·0± 1·9	48·7± 3·1	58·4	60·8	39·6	0·25	0·28	0·23
15 September	80·4	82·3	69·9	73·8	0·15	0·12	104·8	97·6	64·5	85·4	83·1	56·2	0·23	0·17	0·15
16 October	120·2± 5·7	117·6± 6·6	97·7	97·0	0·23	0·20	149·3± 4·2	148·0± 0·6	103·7± 2·1	108·4	110·1	65·7	0·34	0·34	0·58
17 November	144·2	136·1	101·4	102·5	0·42	0·33	163·0	159·9	112·1	115·5	116·2	79·6	0·41	0·38	0·41
15 December	146·1	142·2	107·9	109·2	0·36	0·30	165·7± 6·2	164·2± 3·2	126·5± 8·9	125·3	125·6	87·5	0·32	0·31	0·46
16 January	146·4	147·4	108·4	112·9	0·3[illegible]	0·31	166·0	164·6	...	127·2	126·8	...	0·31	0·30	...

TABLE VI

Periodical weight per plant

(Average of random eight 3-feet strips till June and six later)

Treatment	1937-38												1938-39											
	Mid May*	Mid-June			Mid-October			†Harvest time			Canes per acre		Mid* May	Mid-June			Mid-October			†Harvest time			Tons per acre	Number of canes per acre
	L+St	L	St	L/St	L	St	L/St	L	St	L/St	Tons	No.	L+St	L	St	L/St	L	St	L/St	L	St	L/St		
Series I																								
N—300 N+No P_2O_5	120	273	254	1·07	474	1299	0·36	332	1451± 113·4	0·23	46·1± 3·57	32107	129	350	346	1·01	471	1658	0·28	288	1850± 62·0	0·16	46·2± 1·7	25410
NP—300 N+100 P_2O_5	126	344	379	0·90	461	1350	0·34	295	1473± 28·2	0·20	61·5± 1·18	42108	179	362	357	1·01	460	1578	0·29	355	1766± 48·1	0·20	49·2± 1·37	28314
P—No N+100 P_2O_5	...	...	...	...	...	...	...	...	...	...	...	...	124	272	164	1·66	282	894	0·31	183	1236± 148	0·15	25·2± 3·18	20691
Series II																								
NP—450 N+100 P_2O_5	...	327	368	0·88	475	1567	0·30	324	1595± 48·0	0·20	53·4± 1·64	34122	...	359	368	0·98	515	1665	0·31	301	1621± 176·5	0·19	52·1± 3·79	33396
N_2P—450 N+150 P_2O_5	...	296	344	0·86	416	1306	0·32	284	1550± 72·6	0·18	49·4± 2·29	32307	...	275	277	0·99	498	1544	0·32	260	1729± 289·5	0·15	51·6± 6·2	29766
NP—600 N+100 P_2O_5	...	324	319	1·01	479	1419	0·34	328	1556± 36·6	0·21	61·5± 1·56	40293	...	...	...	...	...	...	...	...	...	...	...	...
N_2P—600 N+150 P_2O_5	...	309	378	0·81	452	1372	0·33	335	1438± 30·0	0·23	60·0± 1·25	42108	...	...	...	...	...	...	...	...	...	...	...	...

L = Leaves
St = Stem
* There was no cane formation in May
† Harvesting was done in February except in no nitrogen+100 lb. P_2O_5 when it was done in January

acceleration of growth eventually attaining the same level of height as in the other one. The low ratio of millable to non-millable portion of cane in the phosphatic treatment is, in fact, suggestive of the slowing down of growth at later stage in this treatment. This is further confirmed by the periodical weights of millable canes as well as the ratio of these to green leaves (Table VI, series I). It would be seen that the weight per cane in the treatment of N has been throughout low till October and it is only due to later growth in this treatment that it has equalled the other one at harvest time. The weight of the functioning leaves is also higher at this period. As would be shown later, more than 50 per cent of the total uptake of nutrients is taken up during the rapid-growing period after earthing and it seems that as a result of less number of canes in this treatment, the competition between plants for the available nutrients is much less than in the other case. The higher rate of increase in growth per plant after earthing up in this treatment would be thus quite explicable. This acceleration of growth has not been, however, sufficient to make up for the reduction in the number of canes per acre and as a result there has been a distinct fall in tonnage in this treatment.

On the other hand, during the season of 1938-39, as in the case of tillering so also in the case of growth, the nitrogenous treatment has not shown any distinct beneficial effect of the basal dose of phosphate. The figures for heights (Table V, series I) as also of weights (Table VI, series I) are practically similar in both the treatments. The increase in the number of canes as well as tonnage per acre at harvest time are not also significant. These data, therefore, indicate an initial sufficiency of phosphate in the soil, the reason for which is already explained. In the case of the third treatment (No nitrogen + 100 lb. P_2O_5) unlike tillering, growth has suffered even from the beginning, clearly bringing out the importance of nitrogen for this phase in the life-cycle of the plant. There is not only a fall in height ; but both the number of mature internodes as well as circumference have also suffered. Otherwise in all other treatments, the data for these two items among botanical observations are practically similar even during the season of 1937-38 and as such these figures are omitted from Table V in order to keep its size within limited dimensions.

As regards series II, although it is primarily meant for finding out the effect of an additional dose of 50 lb. P_2O_5 applied at earthing on the maturity phase, its influence on growth as compared to the basal dose of 100 lb. P_2O_5 alone has also been studied by periodical botanical observations and green weight as in series I. The data, however, do not show any variation of sufficient magnitude between the figures for both heights of millable canes and plant weights owing to this additional dose and it seems, therefore, that this additional dose has not been of any advantage to the plant growth. It does not seem to be also far in excess of the amount required by the plant so as to produce a depressing effect on yield as observed by Russell [1923] and Wallace [1926] in other crops. In Table VI only the figures of plants' weights are given under series II while the figures of heights of millable canes are omitted in this case.

Leaf area. During periodical harvesting of plants for the determination of weights and mineral uptake, eight randomly selected green leaves per strip, i.e. 64 leaves during early stages and 48 later were taken per treatment for the measurement of their length and breadth.

The average product of these per leaf was taken for calculating the total leaf area per plant and on the strength of these data percentage variation in the different treatments from the control (N) was calculated. These results are given in Table VII.

TABLE VII

Per cent variation in the leaf area from that of the control (N)

(Based upon 64 randomly selected green leaves till mid-June and 48 later on)

Periods	1937-38	1938-39	
	300 lb. N + 100 lb. P_2O_5	300 lb. N + 100 lb. P_2O_5	No N + 100 lb. P_2O_5
Mid-May	+17·5	+35·4	+53·7
Mid-June	+32·4	+6·5	—29·2
Mid-October	+4·4	—2·5	—43·5

The above figures clearly indicate the beneficial effect of phosphate at early stages during both the seasons. During the season of 1937-38, the effect continued practically throughout the life-cycle of the plant, while in the latter season it was only short-lived. The reason for this is already explained. The importance of nitrogen at later stages is clear from the data of the treatment P which received no nitrogen.

Photosynthesis. The rate of photosynthesis was determined on the topmost fully developed leaf of the crown directly in the field on the standing plant by the Ganong's punch method [1908]. This leaf was selected as it showed the highest rate of photosynthesis among all the green leaves. It is, no doubt, realized that this method does not represent the total weight of the product formed by photosynthesis during this period. Translocation of products from the leaf must be going on during this period, so also a certain amount of the product must be utilized in respiration which is proceeding simultaneously with photosynthesis. It may, therefore, be said to give the apparent rate of photosynthesis. None of the methods, however, devised for the measurement of photosynthesis can be considered to be quite satisfactory and this was specially selected as it enables one to work it conveniently under natural environmental conditions on the standing plant of such a height.

The results are given in Table VIII for the first series only. The superiority of phosphate during the season of 1937-38 is quite evident. Unfortunately these estimations were not continued during this season after mid-August and, therefore, the further effect of phosphate on this aspect of the plant behaviour remains unravelled. This can be, however, deduced from the growth phase of the crop discussed previously and if increase in weight can

be taken as the resultant effect of the photosynthetic activity of the plant, these figures for the rate of assimilation in these treatments would show a reverse order in later determinations.

The results for the season of 1938-39 for the above-discussed two treatments are practically similar. It is only in the case of the third treatment (No nitrogen + 100 lb. P_2O_5) in which a high rate of carbon assimilation is observed at both mid-May and mid-August with a fall later. Gregory and Baptiste [1936] have also reported high sugar content in leaves in their experiments with barley not receiving any nitrogenous manuring. They have explained this as due to high assimilation, low respiration, low protein synthesis and low meristematic activity. In the present case the tiller numbers are even slightly higher in this treatment (Table IV) and from this standpoint the meristematic activity cannot be said to be lower. No doubt in the case of increase in height per plant, there does seem to be slight decrease in this activity of the plant which would lead to decreased translocation; but on the whole, this would not account for such a large figure of per cent increase as obtained in this treatment for mid-May. The question of differential protein synthesis should also not arise as in this method the rate of assimilation would, in fact, reflect increase in total organic matter. Respiration is not determined and it would be, therefore, a moot point as to how far its decreased rate would be responsible for this high figure. For the present we shall have to be satisfied with attributing this high figure to two factors, viz. (1) high assimilation and (2) low respiration.

In the case of the second series, the figures for both the leaf area as well as carbon assimilation are fluctuating with no clear differentiation between the treatments and, therefore, owing to exigencies of space, the data are omitted from presentation.

TABLE VIII

Rate of photosynthesis

(Per cent increase in weight at 3 p.m. over samples taken at 8 a.m. by Gano's punch method)

(Average of 10 randomly selected plants)

Treatment	Per cent increase in weight		
	Mid-May	Mid-August	Mid-October
1937-38			
300 N+No P_2O_5 . . .	11·9	7·1	..
300 N+100 P_2O_5 . . .	16·7	13·7	..
1938-39			
300 N+No P_2O_5 . . .	5·71	6·3	11·3
300 N+100 P_2O_5 . . .	5·10	8·5	9·0
No N+100 P_2O_5 . . .	26·90	9·4	2·2

Root system. The effect of phosphate on the development of roots has been studied in another experiment in an adjoining block with different forms of phosphatic manuring as superphosphate, bone meal and Nicifos, a nitrogenous top-dressing of 300 lb. N being common to all. These data have been already discussed in detail in a previous paper by Rege and Wagle [1941]. In general, it may be stated that except in the case of Nicifos, there is a favourable effect of phosphatic manuring on the root development. This is quite striking in the treatments of superphosphate and bone meal in which their quantities are applied in two equal doses of 50 lb. P_2O_5—one at planting and the other at earthing—while all the phosphate applied in one dose of 100 lb. P_2O_5 at planting in the form of superphosphate alone has not been so very effective. Nicifos has completely failed to produce a favourable effect on the root system.

Flowering. The data for flowering were collected at harvest time during the cutting of the strips for growth studies. This is given in Table IX.

TABLE IX

Flowering data at harvest time

Treatment	1937-38			1938-39		
	Total number of flowered plants	Total number of non-flowered plants	Per cent of flowered	Total number of flowered plants	Total Number of non-flowered plants	Per cent of flowered
Section I						
300 N + No P_2O_5	44	10	81·5	38	4	90·5
00 N + 100 P_2O_5	42	3	93·3	43	4	91·5
No N + 100 P_2O_5	...	...	...	33	1	97·1
Section II						
450 N + 100 P_2O_5	48	13	78·7	29	19	60·4
450 N + 150 P_2O_5	25	34	42·4	28	20	58·3
600 N + 100 P_2O_5	25	36	41·0	...	...	...
600 N + 150 P_2O_5	23	48	32·4	...	...	...

It would be seen that during the season of 1937-38 the basal dose of phosphate has in the case of 300 lb. N led to the increase in flowering. This is quite in consonance with the growth behaviour in this treatment. On the other hand, the application of an additional dose of 50 lb. P_2O_5 at earthing besides the basal dose of 100 lb. P_2O_5 has led to the reduction in flowering in higher nitrogenous top-dressings as 450 and 600 lb. N. On the face of them these results seem to be quite contradictory. That they are not so will be shown when the mineral uptake will be discussed later. During the season of 1938-39, no such differences in flowering have been observed between the treatments in both the series.

Maturity. This is determined by the periodical brix and purity of the juice and all the results are given in Table X. The figures of brix are also graphically represented in Fig. 1. It would be seen that during the season of 1937-38, the figures for brix are higher in the phosphatic treatment from the start (mid-September) in series I. It is only at the end of February that the treatment of nitrogen alone has come equal to it, when both the treatments have shown the maximum brix attained during this season. The maximum purity is reached a fortnight later in both the treatments.

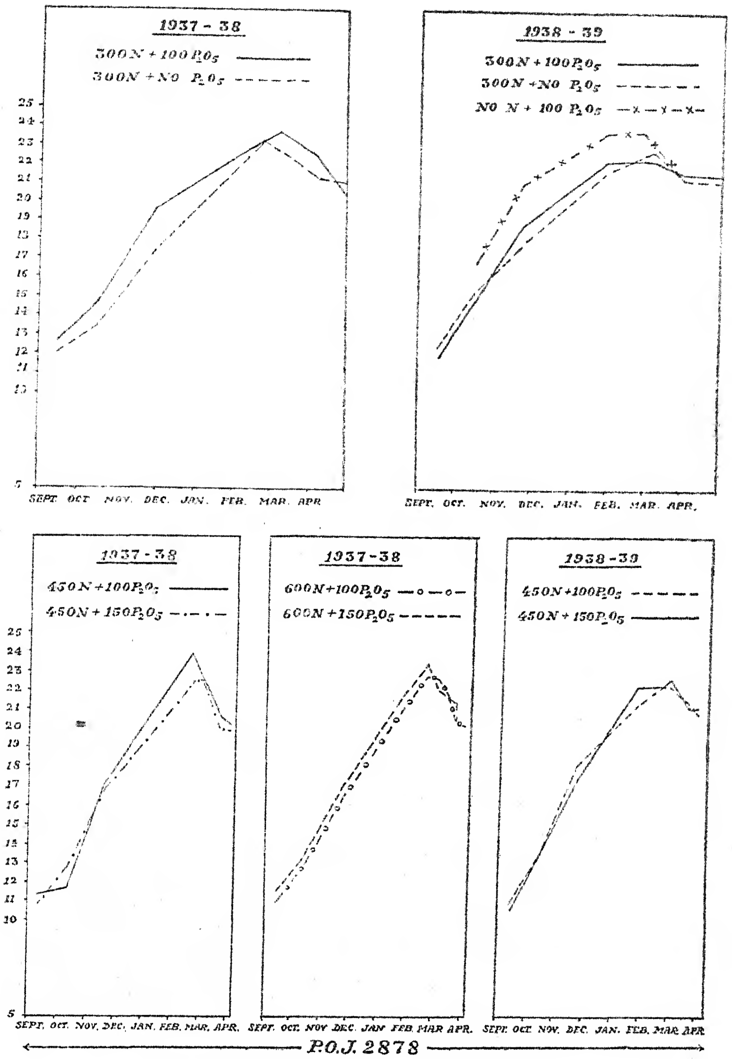

Fig. 1. Periodical brix data at 17·5°C.

There is further an indication of slower deterioration in the keeping quality of cane after the attainment of maximum brix in the case of phosphatic treatment than in the other one. During the season of 1938-39, the periodical data do not show such distinct delaying of the maturity in the case of nitrogen alone as was observed during the previous year. There is some slight beneficial effect of the phosphatic treatment which will not be, however, of economic value. Only the third treatment has shown the earliest maturity which can be ascribed to the deficiency of nitrogen. Other workers as Deer [1921], Cross [1925] and Sanyal [1928] have found the beneficial effect of phosphate from the standpoint of early maturity. It seems, however, that once there is

TABLE X

Data of periodical brix and purity percentages

Treatment	15 September	15 October		23 November		27 January		23 February		9 March		8 April		18 April	
	Brix at 17·5°C.	Brix at 17·5°C.	Purity per cent	Brix at 17·5°C.	Purity per cent	Brix at 17·5°C.	Purity per cent	Brix at 17·5°C.	Purity per cent	Brix at 17·5°C.	Purity per cent	Brix at 17·5°C.	Purity per cent	Brix at 17·5°C.	Purity per cent
1937-38															
Series I															
300 N + No P_2O_5	12·1	13·5	70·5	18·4	...	21·4	...	23·4	88·91	22·6	92·0	21·3	90·3	21·0	88·6
300 N + 100 P_2O_5	12·7	14·7	72·1	19·5	...	22·1	...	23·4	89·32	23·5	94·0	22·3	92·8	20·3	91·1
Series II															
450 N + 100 P_2O_5	10·9	12·7	54·0	16·9	...	20·9	...	22·4	86·52	22·5	92·9	20·1	90·0	19·9	89·5
450 N + 150 P_2O_5	11·4	11·7	53·2	17·1	...	21·9	...	23·9	89·27	22·6	91·2	20·7	89·9	20·2	87·6
600 N + 100 P_2O_5	10·9	12·8	53·4	16·4	...	21·2	...	22·8	86·31	22·6	87·4	20·4	89·2	20·2	88·1
600 N + 150 P_2O_5	11·5	13·1	53·5	16·8	...	21·7	...	23·4	88·40	22·3	87·3	21·4	87·4	20·2	85·1
1938-39															
Series I															
300 N + No P_2O_5	12·5	15·4	71·4	17·8	81·4	21·6	91·4	22·6	89·1	22·9	90·8	21·3	90·3	21·2	...
300 N + 100 P_2O_5	11·9	14·8	77·7	18·7	82·8	22·2	91·0	22·2	88·9	22·1	91·4	21·6	90·9	21·5	...
No N + 100 P_2O_5	...	16·9	78·8	21·0	88·3	23·8	90·9	23·8	89·7	23·1	89·7	21·3	91·5	...	...
Series II															
450 N + 100 P_2O_5	10·7	13·4	58·0	18·0	81·1	21·3	91·7	22·2	86·8	22·3	92·9	21·3	90·0	20·8	...
450 N + 150 P_2O_5	10·5	13·4	65·5	17·3	77·4	22·2	92·0	22·2	86·3	22·5	91·2	21·2	89·9	21·2	...

a sufficiency of phosphate in the soil, an application of a basal dose of phosphate is not in any way effective in hastening the maturity further.

In the case of series II, the additional dose of 50 lb. P_2O_5 at earthing has shown some higher brix and purity during the early readings specially during the first year. The figures are not, however, of outstanding merit to be of economic value.

Mineral nutrition

The material from periodic harvestings of the different treatments was used for this investigation. In order to avoid any inconsistency in the analytical data owing to the translocation of the different constituents, the time of sampling was kept the same throughout. Immediately after weighment, average bulk samples of finely cut leaves and stems were kept for drying in a chamber at a temperature of about 60°C. After drying, these were finely powdered and stored for analysis. Care was taken to remove leaves from the plants as they dried and these were also taken for analysis separately in order to get a complete idea of the total removal of the mineral nutrients by the plant. The roots were not included in these studies, as the soil being a very heavy clay, the collection of roots free from clay particles was found to be impossible.

Besides the ultimate analysis of the material, sap from fresh samples of green leaves was analysed for different nitrogenous fractions. For these determinations, 100 gm. of average samples of leaves were immediately cut into small pieces. These were then crushed in a mortar after mixing with well-washed sand to break the cells and then pressed through a laboratory press at a definite pressure. The determinations of ammonia and nitrate were done immediately on the fresh sample while in the case of other fractions, the fresh material was autoclaved in order to kill the enzymatic activity and then taken for extraction of the juice as time permitted.

Standard A. O. A. C. methods of analysis were employed for the determination of nitrogen, phosphates, potash and calcium in dried material. In the case of leaf sap, ammonia was determined by steam distillation with magnesium oxide and the residual solution was utilized for the determination of nitrate by reduction with Devarda's alloy to ammonia. For the determination of crystalloid and total nitrogen, the method recommended by Richards and Templeman [1936] was followed. The material was thoroughly ground in a mortar with phenol water and filtered through paper pulp. In half the aliquot total nitrogen was estimated after previous reduction of nitrate with reduced iron. In the case of the other aliquot protein was removed with 50 per cent trichloracetic acid after filtering through chamberland filter. In the filtrate, total crystalloid nitrogen was determined also after previous reduction of nitrate with reduced iron.

Water content of the leaf. Instead of giving the actual figures of the water content of the leaf, these are represented in relation to the leaf area and dry weight of the leaves on the lines of Gregory and Richards [1929] in Table XI. Owing to heavy lodging of the crop as a result of late rains during the season of 1938-39, no reliable data could be collected about this at the time of harvest and, therefore, figures for this period are not given. It will be seen that both from the basis of unit leaf area as well as the dry weight, the water content of

the leaves in the NP treatment appears to be higher at the early stage of development (mid-May sample) during both the years. From the standpoint of the climate, this is the period when the plant is subjected to great stress owing to high temperatures and low humidity and when, as a result of these environmental conditions, the water requirement of the plant is found to be the highest. At this period practically all the varieties show incipient wilting while some of the varieties as Pundia and Co 419 even show the phenomenon of tip drying. The influence of phosphates in retaining the higher water content at this period both on the basis of leaf area and dry weight should therefore prove advantageous in the growth phase and this is, in fact, confirmed by the figures of increase in height as discussed previously. These data at later stages of growth do not show any consistent trend in both the years although there are indications of the fall in the water content in the phosphatic treatment during the season of 1937-38.

The ratios of dry weight to leaf area are also interesting in both these treatments as they clearly show that although the leaf area increases as a result of a basal dose of phosphate, there is not a proportionate increase in the dry weight. In other words the leaves get broader but thinner with the application of phosphate. Although chlorophyll was not determined in these treatments during these two seasons, its determination done during later years in similar treatments has shown it to be less throughout the growth phase in the phosphatic one than in the treatment receiving nitrogen alone. The higher rate of photosynthesis as a result of phosphatic application (Table VIII), however, suggests that both the lower dry weight as well as the lower chlorophyll content in the leaves do not in any way act as deleterious factors in this activity of the plant.

In the third treatment (P) the water content calculated on the basis of leaf area does not show the same trend as when calculated on the basis of dry weight. The latter practically agrees with the similar ratios for other treatments, while the former is much lower. These results indicate that for comparative studies the water content calculated on the basis of dry weight will be better than the other one. On the other hand, Gregory and Richards [1929] have shown the ratio of water content to leaf area to be better as it has given more consistent results in their experiments. Further work with a large number of treatments will be, therefore, necessary to elucidate this point.

Uptake of mineral nutrients. The data for N, P, K and Ca obtained on individual analysis of green leaves, dry leaves and stems were calculated and studied in more ways than one, e.g. per 100 gm. of each part of the plant, per 100 gm. of the whole plant, on whole plant basis as well as on acre basis. These results are illustrated graphically in Figs. 2, 3 and 4 for both the seasons. It would be seen that the percentage figures for the parts of the plant as well as the whole plant show a definite fall with the progress of growth, the largest fall being during the grand period of growth. Among the different organs the fall is generally more in the case of stems than in green leaves. This would be quite explicable on the basis of the relative increase in weight in these organs during this period. The curves for dry leaves clearly indicate that as the leaves dry, there is a translocation of nitrogen, phosphate and potash from these leaves to other parts, the highest translocation being in the case of phosphates. This rapid redistribution of phosphate seems to be the reason

TABLE XI

Water content of the leaf

Treatment	Mid-May			Mid-June			Mid-October			Harvest time		
	Water / Leaf area	Water / Dry weight	Dry weight / Leaf area	Water / Leaf area	Water / Dry weight	Dry weight / Leaf area	Water / Leaf area	Water / Dry weight	Dry weight / Leaf area	Water / Leaf area	Water / Dry weight	Dry weight / Leaf area
1	2	3	4	5	6	7	8	9	10	11	12	13
1937-38												
N—300 N+No P_2O_5	0·248	3·57	0·0358	0·233	4·37	0·0534	0·205	2·41	0·085	0·14	2·20	0·064 0·204
NP—300 N + 100 P_2O_5	0·262	4·00	0·0300	0·220	3·96	0·0560	0·205	2·96	0·071	0·12	2·02	0·061 0·183
1938-39												
N—300 N + No P_2O_5	0·202	3·03	0·096	0·202	3·93	0·0607	0·210	2·57	0·082	...	...	...
NP—300 N + 100 P_2O_5	0·312	3·68	0·085	0·230	3·97	0·0580	0·215	2·80	0·077	...	...	...
P—No N + 100 P_2O_5	0·197	3·47	0·057	0·196	3·08	0·0810	0·194	1·94	0·100	...	...	...

$\frac{\text{Weight of water}}{\text{Leaf area}}$ = gm. of water per sq. in. leaf surface

$\frac{\text{Dry weight}}{\text{Leaf area}}$ = gm. of dry weight per sq. in. leaf surface

$\frac{\text{Water}}{\text{Dry weight}}$ = gm. of water per gm. of dry weight

of the smallest amount of phosphate required by the plant. In the case of calcium no translocation during the process of drying is visible and this would explain the necessity of its continued uptake per plant till harvest time.

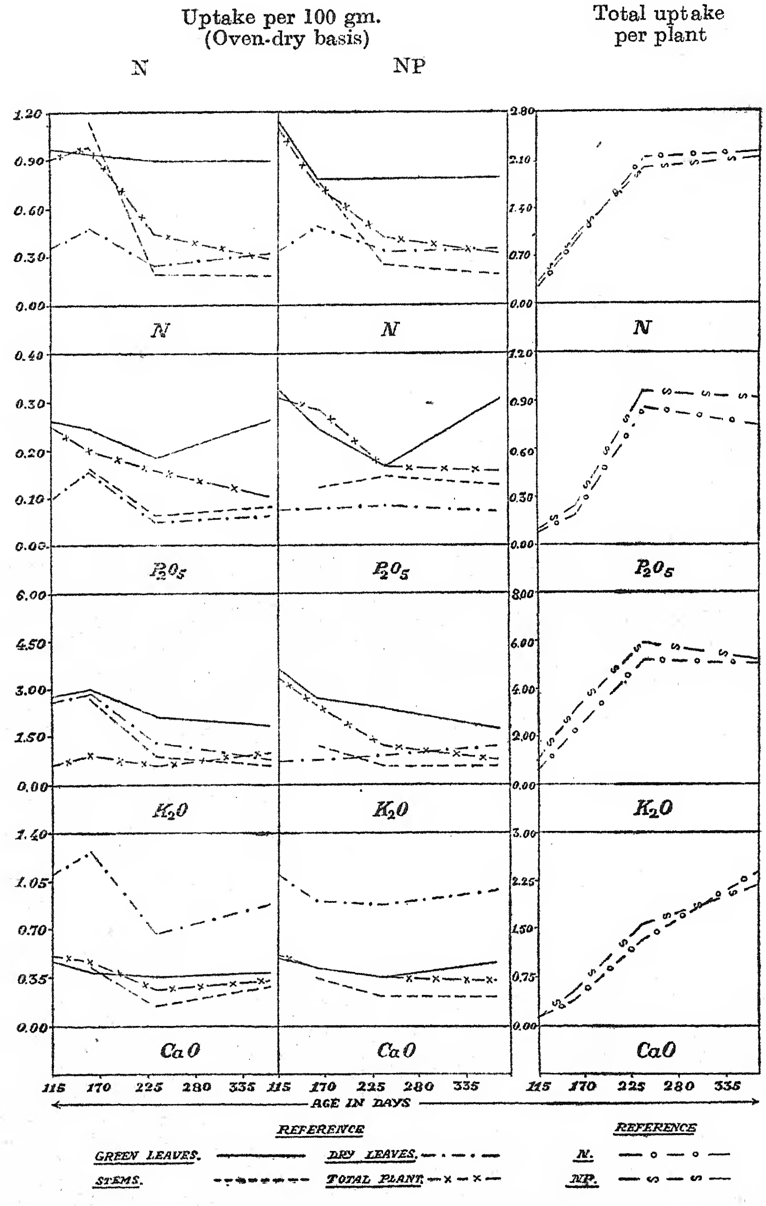

FIG. 2. Variety POJ 2878, 1937-38

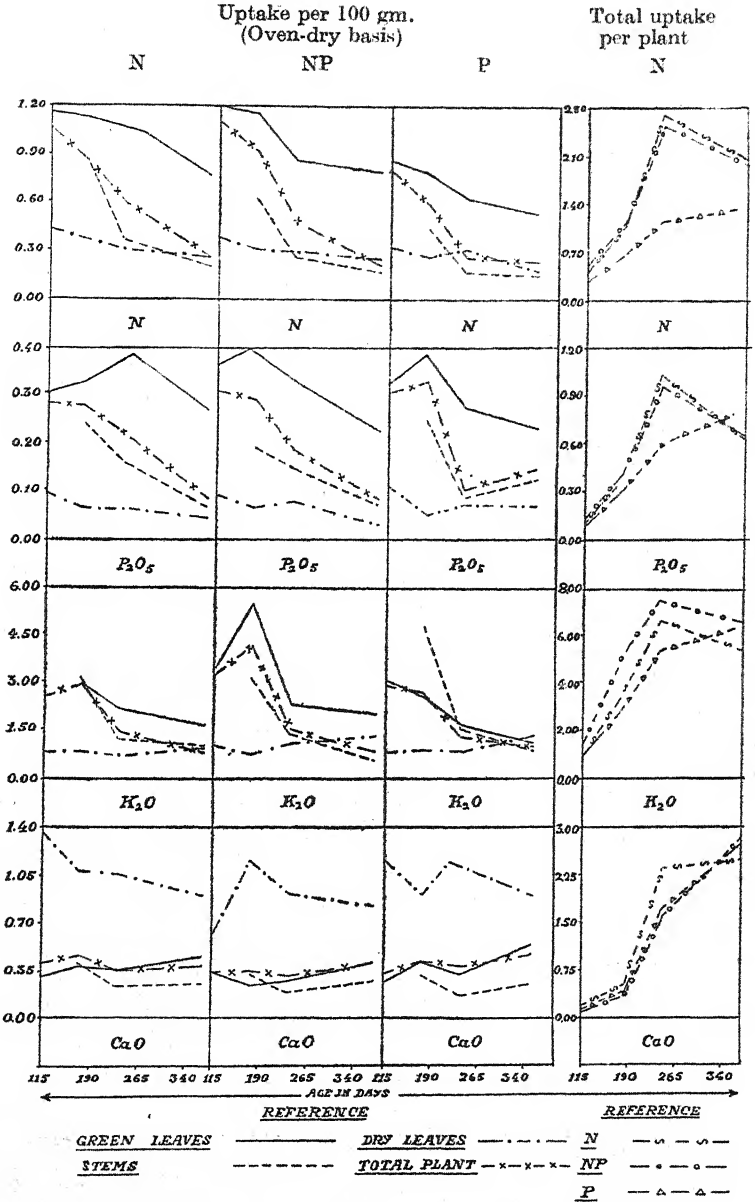

FIG. 3. Variety POJ 2878, 1938-39

For the proper evaluation of the effect of different treatments, the curves for the total uptake per plant and also per acre would be the best guide. In this case the percentage figures will be, in fact, misleading as the total uptake is circumscribed by the actual weight or the number of canes. Although the plant may show poor growth, the percentage figures may be either equal or in some cases even higher than in the case of vigorous plant. This is very well

illustrated in the case of treatment P in which although the figures for percentage constituents are practically similar to those of other treatments the periodical uptake per plant and specially per acre has been less. One interesting feature of these curves is the continuation of uptake of all the constituents after October, when in the case of the other treatments, the curves show a definite fall. This is inexplicable on the basis of the present knowledge and requires further investigation.

As regards the other treatments, NP shows an acceleration of uptake of all the constituents during theea rly stages. In the case of phosphate, this, however, continued throughout the life-cycle of the crop during the first season only, but was not visible during the following one. The high figures for potash in this treatment during both the seasons reveal that phosphate exerts a great influence on the uptake of potash. Russell [1937] has also stated that in the leaves of crops of vines and tomatoes, the percentage of K_2O in the dry matter rises when phosphate is supplied. The comparison of all the curves for the two seasons given in Figs. 1 and 2 shows the higher uptake during the second season whether considered on percentage basis or per plant. As, however, the differences in the plant population per acre between the two years are rather wide, it would not be possible to definitely ascribe the increased

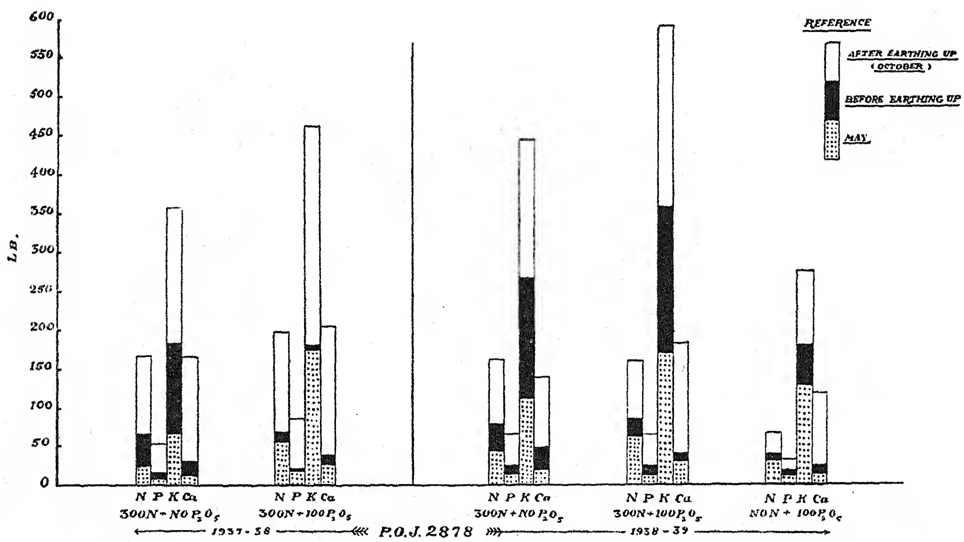

FIG. 4. Periodical and total uptake of N, P, K & Ca per acre

weight per plant as well as the increased uptake during the second season either to the climatic variation or to the residual effect on superphosphate applied to the previous crop of sugarcane.

Fig. 4 represents the total as well as periodical uptake per acre. All the pillars represent maximum uptake, i.e. till October in most cases. It would be seen that the maximum uptake per acre is of potash followed by that of nitrogen while in the case of phosphate it is the least. As regards the treatments, NP has shown higher uptake during the season of 1937-38 which is

chiefly due to the higher yield per acre in this treatment. This effect is not observed during the next season except in the case of potash. In the case of treatment P, the total uptake is much less than in the other treatments. As regards the periodical uptake, it is found to be negligible during the first four months till mid-May. It is only after this period that the rapid absorption of all the constituents starts, more than 50 per cent of the total absorption being observed from July onwards till October after which there is a fall.

In the case of series II, the analysis for mineral constituents were done from October onwards and the figures for the whole plant are given in Table XII.

TABLE XII

Mineral constituents per plant (gm.)

	October				Harvest			
	N	P_2O_5	K_2O	CaO	N	P_2O_5	K_2O	CaO
1937-38								
NP—450 N + 100 P_2O_5 . . .	2·82	0·78	5·24	1·44	2·12	0·92	4·96	2·30
N_2P—450 N + 150 P_2O_5 . . .	3·02	0·77	6·59	1·65	2·14	1·11	4·25	2·19
NP—600 N + 100 P_2O_5 . . .	2·32	0·66	5·22	1·41	3·12	0·82	5·14	2·60
N_3P—600 N + 150 P_2O_5 . .	3·33	0·74	6·00	1·63	3·00	0·75	5·54	2·42
1938-39								
NP—450 N + 100 P_2O_5 . . .	3·70	1·25	7·90	1·88	1·96	0·73	4·82	2·92
N_3P—450 N + 150 P_2O_5 . . .	4·06	1·53	8·48	1·91	2·32	0·85	4·17	3·35

It would be seen that with the additional dose of 50 lb. P_2O_5 at earthing, the maximum uptake of all the constituents except that of P_2O_5 is increased during both the seasons. In the case of P_2O_5 this increase is not so very evident during the first season. This higher uptake of nitrogen appeared to be the cause of delay in flowering in this treatment in both the seasons, it being quite evident during the first season. There has been, however, no advantage from the standpoint of weight per cane. The differences in maturity are not also of outstanding merit. It seems, therefore, that while this additional dose of 50 lb. P_2O_5 is useful in accelerating the uptake of other mineral constituents specially of nitrogen and potash, this increased uptake of these nutrients has been of no advantage from the standpoint of crop growth mainly due to unfavourable climatic conditions which set in by this time.

Mineral ratios. The calculation of mineral ratios as N/P_2O_5, N/K_2O, etc. for both green leaves do not show any variation of magnitude between the two treatments of N and NP. These data are not, therefore, reported. Between the two seasons, however, the ratio is much narrower in the case of N/P_2O_5 as a result of higher uptake of P_2O_5 during the latter season—the maximum figure being 3·7 in October during 1938-39 as against 5·0 for the former one. No differentiation in growth is, however, observed between these seasons which could be attributed to the variation in these ratios. It, therefore, seems that sugarcane can stand wide fluctuations in the mineral constituents without any detrimental effect on the development of the plant. The

agrobiologic ratio of the three important elements of NPK differs also considerably from the one of Mitscherlich specially in potash, the ratio being 3:1:9 as against his 5:1:2. This may be due to the high potash content of the soil under investigation.

Nitrogen fractionations in green leaves. During the season of 1937-38 detailed analysis of nitrogen fractionations were carried out for the green leaves (Table XIII). As the ammoniacal nitrogen was determined by distillation the figures for the same would contain some amide N as well and as a result the reporting of separate figures for these is not followed. The only outstanding feature is the least amount of protein nitrogen during September which seems to be due to the rapid uptake of inorganic mineral nutrients during this period. By October much of this has been converted into protein nitrogen, the percentage of protein nitrogen being higher in NP treatment than in nitrogen alone. In the case of series II these nitrogenous fractions were determined in October samples only. Owing to higher nitrogenous manuring, protein nitrogen is much lower in this series than in the first one. There has been, however, not much variation in these constituents due to the additional dose of P_2O_5 at earthing. As the figures for other fractionations did not show any variation between the treatments, only protein and crystalloid nitrogen were determined during the second season. These data, however, do not show any differences of sufficient magnitude between the treatments and as such they are not reported.

TABLE XIII

Nitrogen fractions in green leaves

1937-38

Treatments	Series I						Series II			
	300 lb. N						450 lb. N		600 lb. N	
	June		September		October		October		October	
	N	NP	N	NP	N	NP	NP	N_2P	NP	N_2P
Ammoniacal and amide nitrogen	4·05	3·78	3·06	3·99	4·75	5·73	3·30	4·80	5·30	6·80
Nitrate nitrogen . .	1·62	1·35	2·60	2·60	0·88	1·40	1·04	1·20	0·99	0·88
Crystalloid nitrogen .	21·14	19·97	27·10	25·60	15·60	6·20	25·80	32·24	37·20	32·20
Protein nitrogen . .	16·24	11·63	1·60	5·60	23·20	22·20	11·00	7·46	6·30	7·50
Protein nitrogen per cent of total nitrogen	43·40	36·80	5·60	17·90	59·90	78·40	29·90	18·80	14·50	18·90

GENERAL DISCUSSION AND CONCLUSIONS

The reaction of the different phases of plant life to the basal phosphatic manuring is found to vary according to the initial phosphatic status of the soil. During the first season, phosphatic manuring has definitely led to (1) rapid increase in tillering resulting in large number of canes per acre and (2) acceleration of growth at early stages with early senescence which brought

about early flowering and early maturity. It also maintained the water content of the leaf at a higher level at the early stage of development which is of great practical significance, as from the standpoint of climate this is the period of highest water requirement. Phosphate further made the leaves broader but thinner and pale green and the rate of photosynthesis was higher during the early stages.

During the following season no distinct favourable effect of phosphatic manuring was evident, the treatments N and NP showing practically similar behaviour during the various phases of plant life. This experimental work was conducted in the block which had received application of superphosphate and oil-cakes to the previous crop of sugarcane in the three years' rotation and the residual effect of this phosphate seems to have continued even on the next crop of sugarcane. The analyses of the soil samples collected at the time of planting have shown that while the figures of available phosphate were practically similar during both the seasons, being respectively 25·1 and 25·9 mg. per 100 gm. of soil, there had been a definite rise in the level of total phosphates during the second season, the figure being 53·7 mg. for the first season as against 66·4 mg. for the following one. The response of the crop to the phosphatic manuring during the first season and non-response to it in the following one thus reveal the possible initial levels of soil phosphate at which deficiency and sufficiency of phosphate are envisaged.

Trials in outside centres by the provincial department of agriculture and sugar factory management have shown that in soils newly brought under sugarcane cultivation there was a response to phosphatic manuring in many cases, while in others on which sugarcane cultivation was going on for a number of years, no response was observed. This appears to be mainly due to the accumulation of phosphates in the soil from oil-cakes which are used as nitrogenous top-dressings to these crops. Further in certain cases even a deleterious effect of phosphatic manuring was revealed as could be judged either by yield or maturity of cane. The analyses of soil samples in these cases have shown the figure of total phosphate to be above 111 mg. per 100 gm. of soil. Russell [1937] has also reported reduction in crop yield as a result of excess of phosphate. While it will be no doubt presumptuous to draw any definite conclusions with such a small number of figures, they can form a useful basis for future investigations in the determination of the three levels of phosphates at which phosphatic manuring will be (1) beneficial, (2) ineffective and (3) deleterious.

In the case of available phosphate, the similarity of figures of both the seasons suggests a lack of relationship which would be quite intelligible when one would consider the periodical rate of uptake of this constituent by the crop. It has been shown that about 70 per cent of the phosphatic requirement of sugarcane is absorbed during the stage of the grand period of growth which in the case of January-planted cane starts five months after planting. It would be thus reasonable to imagine that owing to the maintenance of proper moisture for bacterial action as a result of short-period irrigation and evolution of CO_2 by roots, there would be an increase in the availability of soil phosphate as compared to the figure given above for the samples collected at the time of planting. This has been, in fact, confirmed by the periodical

analyses of exudates from mid-May onwards in later experiments which definitely revealed increasing availability of phosphate and potash with the progress of time. Some workers have found a correlation between the available soil phosphate and response to phosphate manuring. Keir and Stieglitz [1938] have, however, shown that in order to secure this concordance it would be necessary to consider the nature and the amount of available soil plant food reserves as an important function of the stage in the crop sequence at which the soil is to be sampled. In other words, this concordance can be definitely secured if the soil is sampled at the time of the maximum availability of phosphate. This would be rather a difficult point to determine. Besides, as sugarcane is a long-period crop and as the real uptake starts after about five months of growth, even total soil phosphates are expected to give as good a concordance for this crop as the available one. In order to judge the relative value of both available and total soil phosphates for this purpose, it is, therefore, felt necessary to determine the levels of both available and total soil phosphates for different soil types at which phosphatic manuring will be either good, ineffective or deleterious.

From the standpoint of the biochemical activities of the plant also, the initial phosphatic status of the soil is found to be important. During the first season, phosphatic manuring has not only brought about an acceleration of the uptake of all the constituents (N, P, K and Ca) during early stages, but the total uptake was maintained at a higher level throughout in the case of P and K and was only equalled for the other constituents by the treatment of N alone at harvest time. In the following season, however, there was no difference either in the rate of uptake or the total one in both the treatments of N and NP except in the case of potash whose uptake was definitely higher in the NP treatment ; but when one compares seasons, the higher level of uptake of all these constituents during the second season in both these treatments is clearly revealed. Owing to wide differences in plant population per acre during the latter seasons, it is rather difficult to attribute this higher uptake per plant to the higher level of soil phosphate. Some indication of the advantage of higher level of soil phosphate can be obtained from the mineral ratios which in the case of N/P has been greatly narrowed during the latter year. It clearly proves the greater availability of phosphate with its higher uptake during the latter year and although the nitrogen uptake is also high during this year as compared to the previous one, it has not shown proportionate increase which has been the reason of the low ratio of N/P obtained during this year. From the standpoint of the life processes of the plant, however, no distinct advantage has been observed of this low ratio and it appears that sugarcane plant can stand without any detriment wide fluctuations in mineral ratios.

In the case of heavy nitrogenous manuring, 450 lb. N and above, a second dose of 50 lb. P_2O_5 which was applied at the time of earthing with a view to secure early maturity of cane was found to be ineffective. On the other hand, studies in the mineral uptake have shown greater uptake of nitrogen in this treatment as against the other one which did not receive this additional dose of P_2O_5. No advantage of this higher uptake has been observed, such as for instance, an increase in growth or tonnage and this accumulation of nitrogen

can, therefore, be attributed to luxury consumption. It appears that the plant absorbed this nitrogen at a time when the climatic conditions were becoming unfavourable for growth (October) and as a result the absorbed nitrogen could not be utilized. Perhaps in early plantings this higher absorption of nitrogen due to phosphatic manuring may be much earlier when the climatic conditions would be suitable for growth and as such may be useful for securing higher cane tonnages without at the same time producing detrimental effect on sucrose formation and experimental work on this line is in progress.

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ERRATA

The Indian Journal of Agricultural Science

Vol. XII, Part IV, August 1942

Plate XXI—The Correct letterpress is as follows :—

1. Light sienna 2. Sienna 3. Light red 4. Red 5. Light brown 6. Brownish sienna 7. Brown 8. Reddish brown

Page 530, line 4, *for* ' Densily ' *read* ' Densely '

Page 534, line 25, *for* ' govineing ' *read* ' governing '

Page 552, column 2, first row, *for* ' Shoit ' *read* ' Short '

Page 554, column 2, *for* ' W^1' etc. *read* ' W_1 ' etc.

Page 559, column 3, line 1, *for* ' 9 : 3 : 4 : 1 ' *read* ' 9 : 3 : 3 : 1 '

Vol. XII, Part VI, December 1942

Page 895, line 7, *for* ' $K^1{}_2 \frac{{}^2c}{1-\alpha}$ ' *read* ' $K^1{}_2 \frac{\alpha^2 c}{1-\alpha}$ '

Page 905, line 7, *for* ' R_2^{AS} ' *read* ' $R^{2\ OS}$ '

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VOLUME XIII, PART II

(April 1943)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal

ORIGINAL ARTICLES

ON THE BIOLOGY AND CONTROL OF CODLING MOTH (*CYDIA POMONELLA* LINN.) IN BALUCHISTAN

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(Received for publication on 21 October 1941)

(With one text-figure)

THE codling moth [*Cydia pomonella* (Linn.) : Fam. Eucosmidae : Lepidoptera], one of the worst pests of apples, pears and quinces, is firmly established in many orchards of Baluchistan. Due to the constant ravages of this insect, about 80 per cent of apples are infested yearly in Baluchistan, and a fairly large number of valuable apple orchards have been cut down in the Quetta valley during recent years.

An account of the distribution, status and biology of the codling moth in Baluchistan was published by Pruthi [1938]. A popular account of various control measures advocated against this pest was published by Roy [1941] and the preliminary results of insecticidal tests for codling moth control in Baluchistan have also been described by Mustafa and Janjua [1942]. In view of the seriousness of the pest in this area, detailed studies on the biology and control measures were made by the writers during 1936-40, and the results are presented in this paper.

Distribution

The insect has been recorded from almost all the apple-growing countries of the world. It is a serious pest in Europe, the United States of America, Canada, North and South Africa, Australia, New Zealand, Palestine and Afghanistan. In India the pest occurs only in Baluchistan and the North-West Frontier Province. There is, however, a doubtful record of its occurrence from Dras Ladakh (Kashmir) as well [Fletcher, 1919]. In Baluchistan, the pest is widely distributed in the Quetta-Pishin district and Fort Sandeman (Zhob district) ; it also occurs at Mastung and Kalat.

Introduction of the pest into Baluchistan

Janjua [1938] recorded the codling moth as a serious pest of apples in Afghanistan and the subsequent observations of Dr Taskhir Ahmad, a member

of the Indian Agricultural Delegation to Afghanistan, has confirmed this assumption [Mustafa, Mundkur & Ahmad, 1939]. Till the middle of the nineteenth century, northern Baluchistan was an important province of Afghanistan. Very little attention was then paid to fruit-growing. With the area coming under British control in 1879, encouragement was given to the fruit industry and numerous orchards were established, importing most of the nursery stock from Kandhar, Afghanistan [Buller, 1907]. As a result of this, the Kandhari apple is now a well-established variety in Baluchistan. Also, since 1890, when the railway was extended to Chaman, apples along with other fruits began to be imported on a large scale from Kandhar, and Baluchistan became the distributing centre for India. A still greater impetus was given to this trade by the introduction of ice vans. In view of the nature of the life-history of the pest, the most common mode of its spread from one place to another is through the transport of infested fruit. For the past half century, apples from Kandhar have been coming in regularly and it is presumed that the infested fruit must have brought larvae with them and the pest, finding the climatic conditions and the host-plant ideal for its propagation in Baluchistan, gradually established itself and is now a pest of first rate importance. In view of the short period in which its life-cycle is completed, it is very improbable that the pest can reach Baluchistan while being carried inside infested apples imported by sea from Europe, the United States, North and South Africa, Australia, etc. The writers agree with Pruthi [1938] in believing the codling moth to have been introduced from Afghanistan into India.

Nature of damage

Apples, pears and quinces attacked by the larvae of this pest have holes eaten either into the side or from the blossom or stalk end to the core. Dark masses of 'frass' often protrude from these holes. If such fruit is split open, it will be seen that the seeds have been eaten, the core tunnelled through and that the whole area is black and rotting making the fruit unfit for human consumption. The infested fruit usually presents an emaciated and sometimes stunted appearance and very often falls to the ground even with moderately strong wind.

A form of injury less familiar is the 'sting' injury which results from a newly hatched worm chewing the skin of the fruit without burrowing into it. Sometimes when a larva is unable to bore at a particular place, it leaves it and attacks at another point, thus producing a number of 'sting' injuries on the same fruit. Although these injuries are only skin deep, the fruit is invariably exposed to the attack of fungi and scavenger beetles of the family Nitidulidae from which a healthy fruit is usually immune. Rot sets in as a result thereof and the fruit is spoiled.

It has been ascertained that in the Quetta-Pishin district about 80 per cent of apples are infested by this pest, while at Fort Sandeman (Zhob district) the infestation is about 60 per cent [Pruthi, 1938]. Pears and quinces are also attacked almost to the same extent.

Life-history

Immature stages

The various immature stages and the life-history of the codling moth have been previously described in detail by Pruthi [1938]. Therefore, only the

instars and the moults of the larvae are described here in detail. It has been ascertained that the larva undergoes five moults and thus there are six larval instars. The description of the various instars is as follows :—

First instar. Length of a newly hatched larva is 1·9 to 2·1 mm., head being 0·25 mm. in breadth. Soon after hatching, the larva is dirty-white, but ultimately turns creamy-white ; head and thoracic shield dark brown ; anal plate concolorous with the body ; thoracic legs darker than the body colour ; prolegs concolorous with the body. Body with a few long, white hairs.

Second instar. Length soon after moulting is 3·8 mm., head 0·42 mm. wide. General body colour creamy-white ; head dark brown ; thoracic shield a shade deeper than the head ; anal plate shield-shaped, dark brown ; thoracic legs very dark brown ; prolegs concolorous with the body ; tubercles distinct, light brown in colour, each bearing a single hair ; hairs few, creamy-white, moderately long.

Third instar. Length soon after moulting is 5·7 mm., head 0·52 mm. wide. General body colour creamy-white but gradually acquires a pinkish tinge ; head somewhat pale brown ; thoracic shield dark brown ; anal plate shield-shaped and a shade deeper than the body ; thoracic legs dark brown ; prolegs concolorous with the body ; tubercles distinct, shiny ; hairs moderately long, sparse, white ; spiracles small, round and ringed with black.

Fourth instar. Length after moulting is 7·6 mm., head 0·69 mm. wide. General body colour creamy-white with a pinkish tinge ; head very dark brown ; thoracic shield much darker than the head ; anal plate shield-shaped and light brown ; thoracic legs light brown bearing many bristle-like hairs ; prolegs concolorous with the body ; tubercles conspicuous, shiny and concolorous with the body ; hairs short, white, sparse ; edges of spiracles raised, pimple-like, darker than general body colour. Head, thoracic shield and anal plate bear silky hairs.

Fifth instar. Length after moulting is 8·3 mm. to 9·1 mm., head 0·79 mm. wide. General body colour pinkish-white ; head dark brown, shiny ; mouth-parts brown ; anal plate shield-shaped, darker than the body colour ; thoracic legs creamy-white bearing many bristle-like hairs ; prolegs concolorous with the body ; tubercles inconspicuous, flat, spreading, coarsely pitted, each bearing a long yellow setae ; hairs sparse, white ; spiracles round, small, ringed with black. Head, pro-thoracic shield and anal plate bearing silky hairs.

Sixth instar (full-grown larva). Length 12·9 to 14·6 mm. and breadth 1·75 mm. across the first abdominal segment, head almost as long as wide (1·5 mm.). General body colour bright pink especially on dorsal side ; head dark brown, shiny, spherical when viewed from above ; its surface covered by several pairs of setae ; mouth-parts brown, lighter than head ; antennae three-segmented, the distal end of the first segment having a long hair ; labium and its palpi prominent ; pro-thoracic shield becomes much lighter as the larva advances in age ; thoracic legs dark creamy-white ; prolegs concolorous with the body ; crotchets black and arranged in complete circles, except on the last pair on which they are semi-circular ; anal plate dark, highly chitinized ; tubercles oval, slightly darker in colour than body, coarsely pitted ; spiracles

conspicuous, round, ringed with black. The body bears short hairs arising singly.

Duration of various stages, seasonal-history and number of generations

The seasonal-history of codling moth varies considerably under different climatic conditions. In the United States of America, at certain places, such as the Pacific North-west [Newcomer, Yother & Whitcomb, 1924] there are two broods in a year, while in South-west Idaho [Wakeland & Rice, 1932], Delaware [Selkregg & Siegler, 1928] and Yakima valley [Newcomer & Whitcomb, 1924] there are three broods and in the warmest southern provinces there are even four broods [Van Leeuwen, 1929]. There are two generations and a partial third one of the codling moth in South Africa [Pettey, 1932] and New South Wales [Allman, 1928]. In Canada and England there is one brood, sometimes two broods in a year [Adkin, 1935]. An account of the seasona'-history of the insect in Baluchistan for 1937 has been given by Pruthi [1938]. As a result of our investigations during the last four years, it has been ascertained that there are two generations of the codling moth in the Quetta valley in a year. The studies were started in the laboratory with the first-brood eggs deposited during 1936 and subsequently confirmed by field observations.

First generation

Eggs of the first brood. During 1936, the eggs were first deposited on April 12, but oviposition continued up to May 19. The dates during 1937, 1938 and 1939 were April 9, 15 and 10 and oviposition continued up to May 16, 22 and 20 respectively. They are laid singly but occasionally two or three may be found together. Majority of them are deposited on the upper surfaces of the leaves near a cluster of newly set fruit, but sometimes a few are found on fruit as well. The incubation period varies from 5 to 14 days with an average of 9·3 days. In 1936 it varied from 7 to 13 days, in 1937 from 6 to 14 days, in 1938 from 7 to 13 days while in 1939 from 5 to 14 days. A day or two before hatching, the egg loses its glistening appearance and a black spot appears. This is the head of the young larva, which when ready to emerge, may be seen to move its mandibles to cut through the shell.

Larvae of the first brood. During 1936, eggs commenced hatching on April 25 and continued uptil May 26. In 1937 hatching started on April 23 and continued uptil May 22, in 1938 they commenced hatching on April 27 and continued uptil May 29, while in 1939 hatching was in progress from April 24 to May 25. A newly hatched larva moves about and sometimes nibbles a little of the undersurface of the leaf here and there until fruit is reached. The first-brood larvae enter the newly set fruit either at the calyx or stalk end or at any other point on the fruit. The feeding period of the larvae ranged from 12 to 44 days with an average of 25·5 days; in 1936 it was from 18 to 39 days, in 1937 from 18 to 40 days, in 1938 from 12 to 44 days while in 1939 it was from 16 to 40 days. The larva remains inside the fruit until it is full grown. At the end of the feeding period, the larvae leave the fruit through exit holes and seek some suitable sheltered places under which they spin cocoons. The attack of Quetta borer (*Aeolesthes sarta* Solsky) is common in the orchards of Baluchistan and the galleries made by the grubs of this beetle on apple

stems afford suitable places for the larvae to form cocoons. The cocoons are also found under loose bark of trunk and branches, in cracks of stumps and also in the grasses and other weeds near the base of the trunk. The cocoons spun by the first-brood larvae are thinner than those formed by the overwintering larvae. Before pupating, the larva excavates a short passage for the pupa to wriggle out.

The pre-pupal period, which begins from the time the larva leaves the fruit and ends with pupation, varied from a minimum of 5 days to a maximum of 16 days with an average of 9·3 days. In 1936 it varied from 6 to 14 days, in 1937 from 7 to 12 days, in 1938 from 5 to 18 days while in 1939 it varied from 6 to 15 days.

Pupae of the first brood. During 1936, the first pupation took place on June 9 and the last one on July 7. During 1937, 1938 and 1939 the first pupation was recorded on June 12, 10 and 11 and the last one on July 9, 8 and 18 respectively. The pupal period varied from 7 to 17 days with an average of 11·6 days. In 1936 it varied from 9 to 15 days, in 1937 from 7 to 14 days, in 1938 from 8 to 16 days while in 1939 from 8 to 17 days.

Moths of the first brood. When the moth is about to emerge, the pupa wriggles out of the cocoon, till it reaches the surface through the passage which was previously prepared by the larva. The case splits open and the adult moth emerges leaving about two-thirds of the pupal case protruding from the exit hole. In 1936, the first moths of this brood emerged on June 24 and the last on July 21. The dates of first emergence during the three subsequent years were June 25, 22 and 26 and emergence continued uptil July 20, 24 and 28 respectively. The length of life of the adult varied from 3 to 12 days, the average being 8·6 days during June-July, 1938. The females lived a day longer than the males.

Copulation takes place soon after the adults emerge and lasts from an hour to an hour and a half. Invariably it takes place at night. The pre-oviposition period varied from 2 to 4 days with an average of 2·9 days. The average time of egg deposition was 9·9 days varying from 4 to 14 days. Table I gives the oviposition records for the first-brood moths in 1938.

TABLE I

Oviposition record of first-brood moths, 1938

Observation number	Number of moths	Date of			Number of days	
		Emergence	First oviposition	Last oviposition	Before oviposition	Of oviposition
1	2	June, 22	June, 24	June, 27	2	5
2	9	,, 29	July, 1	July, 3	2	4
3	8	July, 2	,, 4	,, 14	2	12
4	5	,, 3	,, 5	,, 10	2	7
5	4	,, 5	,, 7	,, 17	2	12
6	9	,, 7	,, 9	,, 20	2	13
7	3	,, 19	,, 22	,, 28	3	9
8	2	,, 22	,, 24	Aug., 1	2	10
				Average	2·1	9·0
				Maximum	3	13
				Minimum	2	4

The egg-laying activities of the moths were observed in detail. Oviposition usually occurs just after sunset and as the time of oviposition approaches, there are indications of excitement on the part of the female. After sometime, it becomes quiet when the tip of its abdomen touches the surface on which it rests. It slowly lifts its abdominal tip and lays an egg. This process is repeated until all the eggs are laid. The average number of eggs deposited by the first-brood moths was 41·3—ten females depositing 413 eggs. The maximum number of eggs deposited by a single female was 102.

Life-cycle of first generation. The life-cycle of the first generation varied from 55 to 78 days with an average of 65·2 days. In 1936 it varied from 61 to 78 days, in 1937 from 59 to 73 days, in 1938 from 55 to 72 days while in 1939 it ranged from 57 to 76 days.

Second generation

Eggs of the second brood. During 1936, the first eggs were deposited on June 26 and oviposition continued up to July 25. The dates during 1937, 1938 and 1939 were June 28, June 24 and June 30 and oviposition continued up to July 29, July 23 and August 1, respectively. Majority of the second-brood eggs are laid on the fruit though some are found on leaves as well. The incubation period varied from 5 to 11 days with an average of 8·2 days. In 1936 it varied from 5 to 11 days, in 1937 from 5 to 10 days, in 1938 from 7 to 10 days while in 1939 from 6 to 11 days.

Larvae of the second brood. During 1936, the eggs of the second brood commenced hatching on July 8 and continued up to August 3. In 1937 they started on July 5 and continued uptil August 5; in 1938 they commenced on July 7 and continued uptil August 1, while in 1939 they hatched on July 10 and continued uptil August 7. The young larvae enter the fruits which are by now fairly well developed, near the calyx-end or the stalk-end or from the side, often selecting a place where the fruit is already injured by some physiological or other agency. They enter healthy as well as infested fruit indiscriminately avoiding, however, the exit holes already made by the larvae of the first brood. The feeding period of the larvae ranged from 30 to 50 days with an average of 44·1 days; in 1936 from 30 to 47 days; in 1937 from 36 to 50 days; in 1938 from 33 to 49 days; and in 1939 from 34 to 45 days. When full grown, the larva stops feeding, leaves the fruit and seeks some suitable shelter for spinning its cocoon. During 1936, the first larva came out from the fruit on August 22 and the last one on September 14. The dates on which the first larva came out during 1937, 1938 and 1939 were August 28, 25 and 23 and the last one on September 23, 17 and 20 respectively. Suitable places of shelter for pupation are afforded by the loose bark and burrows made by the Quetta borer on apple stems. The cocoons are composed of interwoven silken threads, almost elliptical in shape incorporating in their walls some trash such as bits of bark, etc. Usually they are found in groups of 5 to 12 sometimes 20 or even more. The larva hibernates in this cocoon in a bent or curled condition and before it pupates, it remodels the cocoon, elongating it and building a long slender passage to the outside for the pupa to wriggle out. Securely enclosed in these cocoons the larvae pass the winter until the approach of the next spring season, when they change into pupae. The pre-pupation period including hibernation varied from 165 to 203 days with an

average of 191·1 days. During 1936-37 it ranged from 181 to 203 days, in 1937-38 from 179 to 192 days, in 1938-39 from 177 to 198 days while in 1939-40 from 165 to 201 days.

Pupae of the second brood. During 1937, the earliest pupation of over-wintering larvae occurred on March 15 and the last one on April 8. During 1938, 1939 and 1940 the first pupation was recorded on March 12, 10 and 14 and the last one on April 9, 8 and 10 respectively. The pupal period varied from 23 to 30 days with an average of 26·8 days. In 1937 it varied from 23 to 25 days in 1938 from 26 to 29 days, in 1939 from 24 to 30 days and in 1940 from 25 to 27 days.

Moths of the second brood. In 1937, the first moths of this brood emerged on April 8 and the last on April 31. The dates of first emergence during the three subsequent years were April 11, April 9 and April 13 and continued up to May 5, May 1 and May 6 respectively. The length of life of adult varied from 8 to 20 days, the average being 11·4 days during April-May 1939. The females lived a day longer than the males. The pre-oviposition period varied from 2 to 7 days with an average of 4·5 days. The duration of egg deposition varied from 6 to 19 days, the average being 11·5 days. Table II gives the oviposition records for the second-brood moths in 1939.

TABLE II

Oviposition record of second-brood moths, 1939

Observation number	Number of moths	Date of			Number of days	
		Emergence	First oviposition	Last oviposition	Before oviposition	Of oviposition
1	3	April, 9	April, 13	April, 15	4	6
2	6	,, 14	,, 17	,, 25	3	11
3	5	,, 16	,, 21	,, 29	5	13
4	6	,, 19	,, 25	,, 28	6	9
5	7	,, 20	,, 24	May, 3	4	13
6	4	,, 23	,, 25	,, 8	2	15
7	2	,, 26	,, 28	,, 10	2	14
8	5	,, 30	May, 3	,, 12	3	12
				Average	3·62	11·62
				Maximum	6	15
				Minimum	2	6

The average number of eggs deposited by the second-brood moths was 35·8—ten females depositing 358 eggs. The maximum number of eggs deposited by a single female was 83.

Life-cycle of second generation. The life-cycle of the second generation varied from 243 to 290 days with an average of 268·9 days. In 1936-37 it varied from 243 to 264 days, in 1937-38 from 259 to 290 days, in 1938-39 from 251 to 287 days and in 1939-40 from 262 to 275 days.

General summary. The summarized data on the important stages in life-history are given in Table III.

TABLE III

Summary of the life-history data of Cydia pomonella *(Linn.), 1936-39*

Stages in life-history	First generation			Second generation		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Incubation period of eggs (in days)	14	5	9·3	11	5	8·2
Larval feeding period (in days)	44	12	25·5	50	30	44·1
Pre-pupal period in days (First generation only)	16	5	9·3	*	*	*
Pre-pupal and hibernation period in days (Second generation only)	*	*	*	203	165	191·1
Pupal period (in days)	17	7	11·6	30	23	26·8
Pre-oviposition period (in days)	4	2	2·9	7	2	4·5
Oviposition period (in days)	14	4	9·9	19	6	11·5
Longevity of adults (in days)	12	3	8·6	20	8	11·4
Life-cycle (in days)	78	55	65·2	290	243	268·9

Natural enemies

In Baluchistan, only one parasite of the larva of codling moth, viz. *Paralitomastix variicornis* (Nees) (Encyrtidae : Chalcidoidea) has so far been observed in small numbers.

The hibernating caterpillars of the codling moth are affected by the extremes of climatic conditions prevailing in the Quetta valley and other parts of Baluchistan. The Indian house-sparrow, *Passer domesticus indicus*, which is a constant visitor of the fruit trees in alarming numbers and is a serious menace to the fruit-growers, sometimes comes to their aid by preying upon the wintering worms that often seek shelter under the bark of the tree-trunks or in the soil around the base of the trees. Occasional hoeing of the soil, therefore, exposes the hibernating larvae and pupae to such birds.

CONTROL METHODS ADOPTED IN BALUCHISTAN

Plan of spraying

Experiments on the control of codling moth were started in the beginning of 1936 and continued for three subsequent years. Four orchards at Quetta in which the fruit had seriously suffered from the attacks of codling moth in previous years were selected for experiments. Each garden contained two distinct blocks each of which was about an acre in size, and grown exclusively under the Kandhari variety and the other under the Kulu variety. The trees were 15 to 18 years old, 16 feet apart and mostly of uniform size. The height of the Kandhari trees was 20 to 25 ft. while that of the Kulu variety was 17 to 23 ft. A block contained 12 rows with 14 trees in each row. These were selected for spraying experiments each year. 'Four Oaks Bridgewater'

spraying machine, armoured rubber hose $\frac{1}{2}$ in. $\times$ 25 ft., bamboo lance 4 ft. long and a double swivel nozzle were used in spraying. In applying the spray, the nozzle was directed in such a way as to get a straight drive into the calyx cups. The trees were sprayed first at the top and then the lower portions by adjusting the nozzle. Spray material at the rate of about two gallons per tree per application was used and this quantity was sufficient to cover the trees thoroughly.

Time of spray applications

In all, one calyx and four cover sprays were applied and the object and timing of these are described as follows :—

(1) *Calyx spray.* The purpose of this spray was to deposit poison in the calyx cups when almost all the petals had fallen off and before the calyx cups had closed. This is an important factor in codling moth control, because the small larvae find the calyx cups convenient places for entering into the fruit. The proper time for the application of this spray was when the calyx lobes had formed into cups, and when approximately 90 per cent of the petals had fallen. The authors believe this spray to be an important one as data at hand have often shown that about 60 per cent of the larvae enter through the calyx cups on unsprayed trees.

(2) *Cover sprays.* Cover sprays are for the express purpose of covering the fruit with a protective material to act as a poison for the larvae at the time they would attempt to enter the fruit. They also serve as a coverage of the leaf surface where many of the larvae can also be poisoned. In all, four cover sprays were applied and their timing was so planned as to give coverage during the hatching of the larvae of each brood.

First cover spray. As the spring-brood moths continue to emerge for about a month, the eggs deposited by them continue to hatch for the same period. The first cover spray was, therefore, applied to kill those worms of the first brood which had hatched out of the eggs deposited in the middle of the egg-laying period. This spray was applied about three weeks after the calyx spray.

Second cover spray. This spray was applied about 10 days after the first cover spray, and is important, because the maximum number of first-brood worms are present in the orchard at this time. Moreover, abundant food is also available to them as the fruit begins to grow rapidly.

Third cover spray. The third cover spray was meant to protect the fruit from the attack of the earliest hatched second-brood worms, which usually start coming out in the first week of July. It was applied 10-12 days after the second cover spray.

Fourth cover spray. The fourth cover spray was scheduled about 20 days after the third cover spray, as at this time, the maximum number of second-brood worms are present in the orchard. If the worms are not under control by this time, later sprays can do little good and will only result in excessive quantities of poison residue being left on the fruit at picking time.

Table IV gives the actual spraying dates together with the blossoming periods of the Kulu and the Kandhari varieties of apples in the four selected gardens at Quetta during the years 1936-39,

TABLE IV

Blossoming periods and spraying dates on Kulu and Kandhari varieties of apples 1936-39

Year	Variety	Full blossom	All petals dropped	Calyx spray	First cover spray	Second cover spray	Third cover spray	Fourth cover spray	Fruit picked
1936	Kulu .	April, 20	April, 25	April, 23	May, 13	May, 23	July, 4	July, 24	September, 20
	Kandh-ari	,, 17	,, 22	,, 20	,, 10	,, 20	,, 1	,, 21	,, 13
1937	Kulu .	April, 18	April, 23	April, 21	May, 11	May, 21	July, 2	July, 22	September, 22
	Kandh-ari	,, 15	,, 20	,, 18	,, 8	,, 18	June, 29	,, 19	,, 15
1938	Kulu .	April, 22	April, 27	April, 25	May, 15	May, 25	July, 3	July, 23	September, 25
	Kandh-ari	,, 19	,, 24	,, 22	,, 12	,, 22	June, 30	,, 20	,, 16
1939	Kulu .	April, 17	April, 22	April, 20	May, 10	May, 20	July, 6	July, 26	September, 23
	Kandh-ari	,, 14	,, 19	,, 17	,, 7	,, 17	,, 3	,, 23	,, 14

Insecticidal tests

During the past half a century, workers all over the world have been engaged in investigating suitable and effective insecticidal remedies against this important pest. Of the numerous insecticides consisting of stomach and contact poisons that have been tested by the various workers, McAllister and Van Leeuwen [1930] have listed no less than 284. These include various arsenicals, organic poisons such as nicotine, oils alone and in combination with arsenates of lead and calcium, nicotine sulphate, etc.; several stomach poisons other than arsenicals including fluorine compounds ; and various stickers and spreaders. Although there is diversity of opinion among the workers regarding the effectiveness of the various insecticides used, a great majority of them still hold that lead arsenate is the most suitable and effective insecticide against the codling moth [Pettey, 1932] chiefly because of its low cost [Sherman III, 1936]. Spraying tests were carried out by us with a number of materials which were tested separately as well as in combination with others. Generally speaking, these insecticides, as is well known, can be divided into two classes—stomach poisons and contact sprays. The arsenicals and fluorides come in the first general group, while kerosene-oil, crude oil, nicotine sulphate (Black leaf '40') and fish oil fall in the second group. Each one of these was given a trial each year with a view to find out the most effective insecticide under Baluchistan conditions. The results obtained are recorded as follows :—

(1) *Lead arsenate.* Tests were carried out with this chemical using 4 lb. of lead arsenate powder to 100 gallons of water with casein as a spreader. When a full course of this spray was given, on the average it reduced the wormy fruit to 25 per cent in the Kulu and 26·5 per cent in the Kandhari variety. Spray residue from apples was removed by dipping in 1·5 per cent hydrochloric acid for two minutes and rubbing with a soft cloth.

The following materials were used in combination with lead arsenate in an attempt to increase its effectiveness or to add to the toxicity of the spray.

(*i*) *Fish oil*. This was used with lead arsenate at the rate of one quart per 100 gallons of the spray on all cover sprays following a calyx spray with lead arsenate alone. The addition of fish oil resulted not only in a better type of coverage on the fruit but also in an increased deposit of lead arsenate. In addition, it had also an ovicidal value. Its application reduced on the average the wormy fruit to 16 per cent in the Kulu and 16·8 per cent in the Kandhari variety. Spray residue was removed by giving the fruit a dip in sodium silicate solution.

(*ii*) *Kerosene oil*. Experiments were conducted to test the efficacy of lead arsenate-kerosene oil combination. The spray was prepared according to the following formula :

Water	2 gallons
Ammonia (concentrated)	2·5 liquid ounces
Casein	4 ounces
Kerosene oil	8 gallons

Ammonia was first added to the water and then casein was dissolved in it after which oil was added slowly and mixed for 20 minutes. The mixture was churned thoroughly for about 20-30 minutes until the oil was thoroughly mixed. One gallon of this kerosene oil emulsion was used in 100 gallons of lead arsenate spray. This combination, when used in all thee fivsprays, reduced the wormy fruit on an average to 16·7 per cent in the Kulu and 17·7 per cent in the Kandhari variety. Although the addition of kerosene oil emulsion to lead arsenate increased the arsenic deposit on the fruit and besides acting as an ovicide, its application resulted in severely burning the leaves, along with partial defoliation of the trees. It had also the additional disadvantage of complicating residue removal.

(*iii*) *Crude oil*. This was combined with lead arsenate in the same proportion and the spray was prepared in the same way as the kerosene oil emulsion. This combination when used in all the five sprays, reduced the wormy fruit on the average to 18·5 per cent in the Kulu and 19·2 per cent in the Kandhari variety. Although this spray proved effective in controlling the worms by killing the eggs and young larvae, it was not superior to lead arsenate when used alone, as it resulted in severely burning the foliage. It had also the disadvantage of complicating residue removal.

(*iv*) *Nicotine sulphate* (Black leaf '40'). This was combined with lead arsenate at the rate of $\frac{3}{4}$ pint in 100 gallons of spray and was applied in all the five sprays. Although there was no foliage injury, it did not materially improve the worm control and the results obtained were almost equal to those got by the application of lead arsenate alone. On the average, it reduced the wormy fruit to 24·5 per cent in the Kulu and 26·2 per cent in the Kandhari variety. The spray residue was easily removed by dipping the fruit in 1·5 per cent hydrochloric acid solution.

Along with these tests, a few trees were kept as control where no spray was applied and on the average there was 78·5 per cent wormy fruit in the Kulu and 80 per cent in the Kandhari variety.

(2) *Calcium arsenate*. This chemical was selected because, next to lead arsenate, its cost, availability, compatibility with fungicides and stability appeared to be most promising of all suggested remedies. Experiments were

carried out using 3 lb. of calcium arsenate per 100 gallons of water with a small quantity of soap as a spreader. When a full course of this spray was given, on the average it reduced the wormy fruit to 27·2 per cent in the Kulu and 27·7 per cent in the Kandhari variety. These results indicated that calcium arsenate spray was not as effective as lead arsenate when used alone. No burning of foliage was, however, experienced. Spray residues from apples were easily removed by dipping them in one per cent hydrochloric acid solution.

Calcium arsenate has the advantage of being cheaper than lead arsenate and can be easily combined with a number of other materials, such as vegetable oils, mineral oils, fish oils, etc. The following materials were used in combination with calcium arsenate in an attempt to increase its effectiveness or to add to the toxicity of the spray.

(*i*) *Vegetable oil.* The vegetable oils tested were linseed, rape and castor oils. Experiments using calcium arsenate with these oils were carried out to find out the most effective combination amongst them. All mixtures were prepared with three pounds of calcium arsenate per 100 gallons of water and 1½ lb. of oil. The oils were churned well in water before adding calcium arsenate. Each combination was used in all the five sprays. The control obtained with linseed oil was in general a little better than that obtained with lead arsenate when used alone and on the average, it reduced the wormy fruit to 24 per cent in the Kulu and 24·5 per cent in the Kandhari variety. This combination had, however, the disadvantage of burning the foliage and affecting the colour of the fruit. Rape oil came next to linseed oil and on the average, reduced the wormy fruit to 24·5 per cent in the Kulu and 25 per cent in the Kandhari variety. This combination also burnt the foliage and affected the colour of the fruit. Castor oil gave poor results by reducing on the average, the wormy fruit to 30·5 per cent in the Kulu and 29·5 per cent in the Kandhari variety. There was, however, no foliage injury. Residues from apples sprayed with these combinations were easily removed by dipping in 1·5 per cent hydrochloric acid solution.

(*ii*) *Fish oil.* This was used with calcium arsenate at the rate of one quart per 100 gallons of the spray on all the cover sprays following a calyx spray with calcium arsenate alone. The combination was equal in efficiency to lead arsenate used alone and, on the average, reduced the wormy fruit to 25·2 per cent in the Kulu and 26 per cent in the Kandhari variety. Although little arsenic injury occurred early in the season on the trees sprayed with this combination, severe burning and yellowing of the foliage took place late in the season. Sodium silicate solution was used for removing the spray residue from apples.

(*iii*) *Kerosene oil.* When kerosene oil was used with calcium arsenate, a high deposit resulted, and the degree of control was better than lead arsenate spray. On the average, this spray, when applied in all five sprays, reduced the wormy fruit to 19·5 per cent in the Kulu and 20 per cent in the Kandhari variety. The kerosene oil emulsion was made with casein-ammonia in the same way as in lead arsenate-kerosene oil emulsion, but the quantity used was half a gallon of the emulsion to 100 gallons of the spray. This spray did not burn the foliage and further the residue was easily removed. Amongst all the calcium arsenate combinations, this has given the best results under our conditions.

Along with these tests a few trees were kept as controls where no spray was applied and on the average there was 78·5 per cent wormy fruit in the Kulu and 77·7 per cent in the Kandhari variety.

(3) *Cryolite sodium aluminium fluoride*). Trials were made with cryolite to find out its efficacy under our conditions. Used in all the five sprays at the rate of 4 lb. to 100 gallons of water, the results obtained were slightly better than lead arsenate used alone. On the average, its application reduced the wormy fruit to 24·5 per cent in the Kulu and 24·2 per cent in the Kandhari variety. Better results were, however, obtained when one pint of fish oil and a small amount of soap were added to the spray as they considerably improved the uniformity of the cryolite deposit. When cryolite-fish oil-soap are used, on the average this spray reduced the wormy fruit to 19 per cent in the Kulu and 19·7 per cent in the Kandhari variety. There was no foliage injury and the residue from apples was easily removed by dipping in 1·5 per cent hydrochloric acid to which 2 per cent boric acid was added.

A few trees kept as controls along with these tests gave on the average 79·5 per cent wormy fruit in the Kulu and 80 per cent in the Kandhari variety.

(4) *Kerosene oil-nicotine sulphate* (*Black leaf '40'*). Tests were made with this combination as a possible substitute for lead arsenate. The formula used was one gallon of kerosene oil emulsion prepared with casein-ammonia and one pint of nicotine shulphate (Black leaf '40') in 100 gallons of water. Experiments have shown that when this combination was used in all the five sprays, poor results were obtained. On the average, it reduced the wormy fruit to 38·5 per cent in the Kulu and 39·2 per cent in the Kandhari variety. Its effect was, however, very greatly increased if lead arsenate was applied on calyx and oil-nicotine combination on the subsequent cover sprays when, on the average, it reduced the wormy fruit to 16 per cent in the Kulu and 16·8 per cent in the Kandhari variety. The outstanding value of this combination was that it proved to be a triple-acting spray as it killed moths, eggs and larvae. The data on oil-nicotine spray as a whole indicate that it can be used to the best advantage on cover sprays where a lead arsenate spray has been given on calyx. It did not burn foliage and the residue from apples was easily removed by dipping first in sodium silicate solution and then in hydrochloric acid solution. On account of the high cost of the ingredients, it is however a costly spray. On control trees, the average wormy fruit produced in the Kulu variety was 80 per cent and in the Kandhari it was 80·5 per cent.

Summary of insecticidal tests

The effect of different sprays on the percentage of infestation is shown in Table V. It is clear from this table that lead arsenate-fish oil combination (series ii) and lead arsenate-kerosene oil emulsion-nicotine sulphate combination (series xv) have proved the most effective sprays, both reducing the wormy fruit on the average to 16 per cent in the Kulu and 16·8 per cent in the Kandhari variety. But comparatively speaking on account of the high cost of the ingredients of the latter combination, it cannot be used on a large scale. Next in effectiveness comes the lead arsenate-kerosene oil emulsion combination (series iii) reducing the wormy fruit to 16·7 per cent in the Kulu and 17·7 per cent in the Kandhari variety. But it has the disadvantage of resulting in

severe foliage burning, sometimes even in partial defoliation. Same was the case with the lead arsenate-crude oil emulsion combination (series iv). Cryolite-fish oil-soap combination (series xiii) also gave satisfactory results, reducing the wormy fruit to 19 per cent in the Kulu and 19·7 per cent in the Kandhari variety. The other combinations did not give satisfactory results. Taking into consideration every aspect of the spray, lead arsenate-fish oil combination has proved to be the best under our conditions.

TABLE V

Effects of sprays on the prcentage of infestation

Serial number	Treatment*	Kulu variety		Kandhari variety	
		Sound	Wormy	Sound	Wormy
i	4 lb. lead arsenate, Casein—Calyx, 4 Cover sprays	75	25	73·5	26·5
ii	4 lb. lead arsenate—Calyx, 4 lb. lead arsenate, 1 qt. fish-oil—4 cover sprays	84	16	83·2	16·8
iii	4 lb. lead arsenate and one gallon kerosene oil emulsion —calyx, 4 cover sprays	83·3	16·7	82·3	17·7
iv	4 lb. lead arsenate and one gallon crude oil emulsion—calyx, 4 cover sprays	81·5	18·5	80·8	19·2
v	4 lb. lead arsenate and ⅜ pt. nicotine sulphate—calyx, 4 cover sprays	75·5	24·5	73·8	26·2
vi	3 lb. calcium arsenate and soap—calyx, 4 cover sprays	72·8	27·2	72·3	27·7
vii	3 lb. calcium arsenate and 1½ lb linseed oil—calyx 4 cover sprays	76	24	75·5	24·5
viii	3 lb. calcium arsenate and 1½ lb. rape oil—calyx, 4 cover sprays	75·5	24·5	75	25
ix	3 lb. calcium arsenate and 1½ lb. castor seed—calyx, 4 cover sprays	69·5	30·5	70·5	29·5
x	3 lb. calcium arsenate and soap—calyx spray. 3 lb. calcium arsenate and 1 qt. fish oil—4 cover sprays	74·8	25·2	74	26
xi	3 lb. calcium arsenate and ½ gallon kerosene oil emulsion—calyx, 4 cover sprays	80·5	19·5	80	20
xii	4 lb. cryolite—calyx, 4 cover sprays	75·5	24·5	75·8	24·2
xiii	4 lb. cryolite, 1 pt. fish oil and soap—calyx, 4 cover sprays	81	19	80·3	19·7
xiv	1 gallon kerosene-oil emulsion and 1 pt. nicotine sulphate (B. L. "40")—calyx, 4 cover sprays	61·5	38·5	60·8	39·2
xv	4 lb. lead arsenate—calyx spray. 1 gallon kerosene oil emulsion and 1 pt. nicotine sulphate (B. L. "40")—4 cover sprays	84	16	83·2	16·8

* Materials used in 100 gallons of spray

Traps

(*i*) *Light-traps*. Experiments were conducted to find out whether codling moths could be attracted to light or not. Six kerosene oil lamps were hung during the four years that the work was in progress every night throughout the season in unsprayed apple plots in two gardens at Quetta. The moths were not attracted to these lamps.

(*ii*) *Bait-traps*. The sprays are only effective if applied at the time when the maximum number of eggs of the two broods are laid in the orchard and are about to hatch. Such periods can be determined if we know when the moths emerge and when the largest number of them are present in the orchard. A

simple method of forecasting such periods is facilitated by a bait-trap, which attracts the moths in large numbers. The construction of such a trap described by Pettey [1932] is shown in Fig. 1, wherein instead of enamel bucket we used an enamel dish.

The following formula was used for the preparation of the bait :—

Molasses . .	one part
Water . .	nine parts
Yeast . .	enough to start fermentation

Since it takes several hours for the fermentation to start, the baits were prepared in the morning and put out in pans in the sun. By evening they were ready for putting on the poles. Two-thirds of each pan was filled with the bait and refilling was done after every week.

Every year 10 bait-traps were placed near the two-thirds height on every fifth tree in an unsprayed apple plot at the Fruit Experiment Station, Quetta. During the season of 1936 a total of 1,088 moths were trapped in them, while their number during the seasons of 1937, 1938 and 1939 was 1,172, 1,093 and 1,105 respectively. Every year a few moths were caught in the beginning of April, but from about the middle of April, their number increased till about the middle of May, followed by a rapid decline. Again only a few moths were caught in the last week of June but the beginning of July registered an increase which continued until the middle of July when there was a decline. In the beginning of September, the use of traps was discontinued as no moths were attracted.

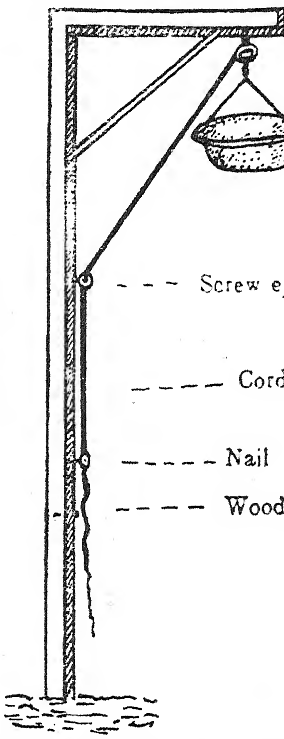

Fig. 1. A simple bait-trap for attracting codling moths (after Pettey)

The information collected from bait-traps helps in timing the spray dates. The actual dates are determined by corroboration with the seasonal activities of the insect. If there is a covering of the insecticide on the fruit during the period the adult moths are caught, most of the larvae hatching from the eggs laid by these moths will be poisoned.

Cost of spraying

The cost per 100 gallons of the most effective spray (4 lb. lead arsenate and 1 qt. fish oil) is Rs. 4-13 and the following gives the approximate expenses incurred per tree during the whole of the season :—

	As.	P.
Spraying materials . . .	7	9
Labour	2	9
Bait-trap	1	6
	12	

The average yield of apples from a full-grown plant in the Quetta valley is about 200 lb. In an unsprayed tree, about 20 per cent of the fruits is healthy and therefore, marketable. A proper course of spraying increases the marketable fruit to 84 per cent. The average price of apples at Quetta is As. 1-6 per lb. and according to this price an unsprayed tree will bring about Rs. 3-12, while a sprayed one will fetch Rs. 15. Thus by incurring an expenditure of annas 12 per tree, the income can almost be raised to four times.

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BACTERIAL SOFT ROT OF TOMATOES CAUSED BY A SPORE FORMING ORGANISM

BY

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(Received for publication on 13 November 1941)

(With Plates III and IV)

IN the summer of 1938 some tomato fruits of a large red variety (Pocha and Sons) on the college students' farm at Lyallpur were found to be attacked with a certain disease. The disease appeared in the form of an under-skin soft rot. In early stages the fruit showed a discolouration which with the advance of infection turned into a brown and wrinkled spot. In extreme cases the fruit was shrivelled and pulpy.

Some specimens of the fruit showing disease in early stages were brought to the laboratory and examined microscopically. The diseased tissue revealed the presence in large numbers of bacterial rods with round ends. With a view to isolate the causative organism platings were made from the infected tissue on nutrient agar of the following composition :

Beef extract	3 gm.
Peptone	5 ,,
Sodium chloride	8 ,,
Agar agar	15 ,,
Distilled water	1000 c.c.
*p*H	6·8

Two different types of colonies were noticed : (*i*) dull white spreading with irregular margin ; and (*ii*) circular, smooth creamy white with even margin.

Transfers were made from the two types but the growth on slants in both cases appeared to be similar. On microscopic examination too, both the cultures were found to be rods with rounded ends and central spores.

INFECTION TRIALS

(1) Some fresh healthy semi-ripened tomato fruits were washed in clean water and the surface sterilized with mercuric chloride (1 : 1000). A portion of the surface was then wiped with alcohol and the fruits inoculated (with gentle needle pricks) in duplicate pairs with each of the cultures separately and in combination. These together with four controls (also pricked with sterilized needle) were incubated under aseptic conditions in sterilized petri dishes at room temperature (about 37°C.).

On the second day lesions became visible in the case of all the inoculated fruits ; these started as brownish spots and later became dark brown and

wrinkled. The infection was so virulent that after three days the fruit became pulpy and in another three days it was totally mashed up with a foul smelling exudate. None of the uninoculated fruits showed any sign of disease.

In the case of the infected fruits the diseased tissue was examined under the microscope and found to be full of rods in every case. The organism was reisolated from the diseased fruits and was found to be similar to the original pathogen in all cases.

(2) Another lot of healthy tomatoes was cleaned as above, a portion of the surface sterilized with alcohol and infected with the culture isolated under (1) above.

The disease appeared as before in the form of an underskin rot which spread rapidly and in four days the fruit was pulpy and mashed up. Plate IV fig. 2 shows the rot in different stages.

The organism

The organism is a rod with rounded ends measuring 0·75μ to 1μ by 1·25μ to 2·5μ, occurring singly. It is motile with peritrichic flagella and produces ovoid central spores measuring 0·75μ × 1·2μ, sporangia not bulged (Plate IV fig. 3). It is Gram positive.

Agar colonies :	Creamy white, raised, shining, amaeoboid or branching with crenate margin (Plate III Fig. 1). In very thick plates roundish flat colonies* were also noticed (Plate III fig. 2)
Agar slant :	Growth creamy white, shining, spreading at the bottom (Plate IV fig. 1)
Gelatine plate :	Colonies circular, growth whitish, liquefaction
Gelatine stab :	Stab visible by whitish growth along it. Liquefaction, crateriform
Broth :	Slightly turbid. Thin pellicle, coherent
Potato :	Growth, brownish, spreading, shining with blackening of the substrate
Litmus milk :	Not coagulated, colour discharged. Slight alkalinity. Separation of whey and settling of casein after prolonged incubation

Indol not formed
Nitrate not reduced
Starch not hydrolysed
Slight H_2S production
Acid from sucrose, dextrose, mannite, arabinose and glycerol
No acid from lactose, maltose, dulcitol and dextrin
No gas from carbohydrate broths
Ammonia produced from peptone
Optimum temperature 40°C. Growth limits 10° to 55°C.
Vegetative cells not killed at 79°C. for 10 minutes
Spores survive half an hour at boiling temperature

*Both the types of colonies were separately plated and were found to be capable of again segregating out by repeated trials. The cultures from these colonies were found to be identical morphologically and physiologically.

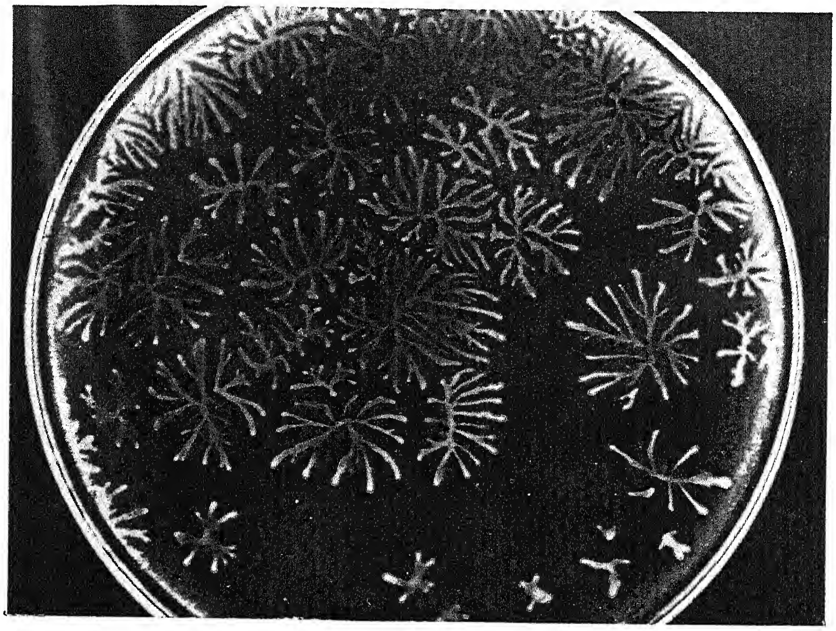

FIG. 1. Colonies on a thin agar plate

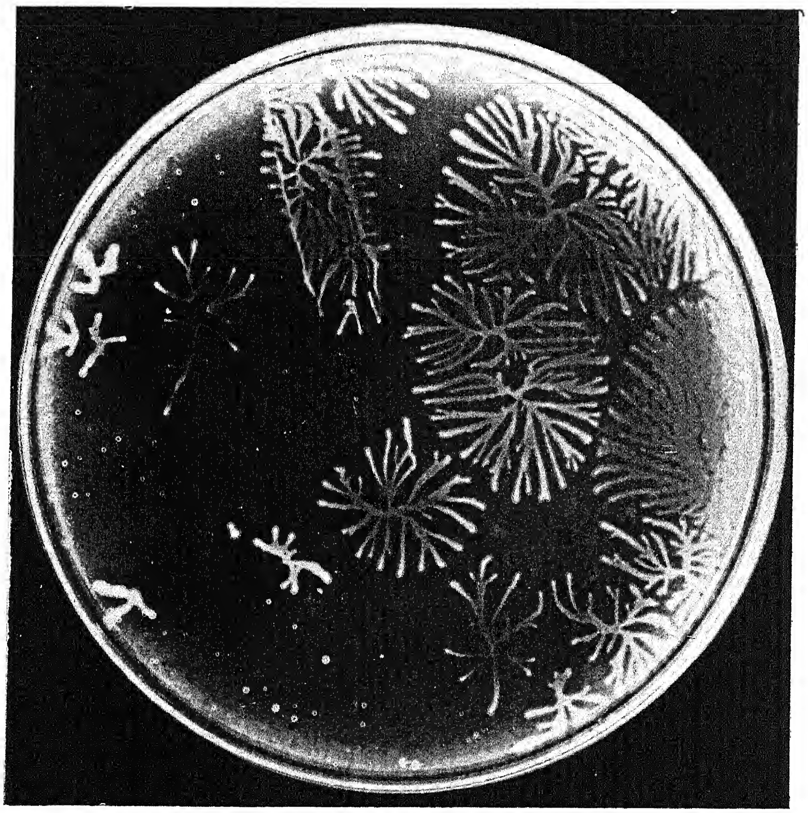

FIG. 2. Colonies on a thick agar plate

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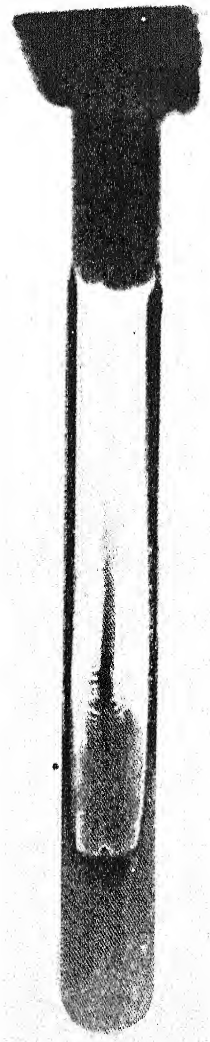

FIG. 1. Growth on an agar slant

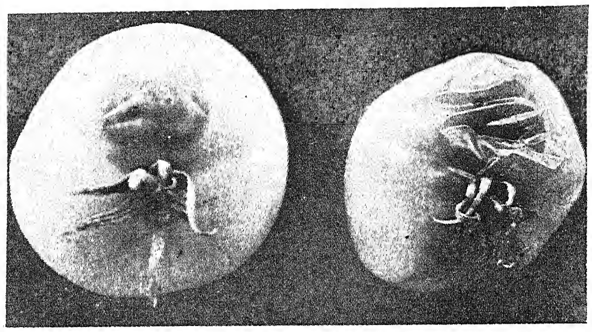

FIG. 2. The rot after three and five days

FIG. 3. The Organism showing central spores

Strict aerobe

NOTE

1. Basic-medium for the carbohydrate media had the following composition, one per cent of the required carbohydrate being added before sterilization in each case:

Beef extract	3 gm..
Peptone	5 ,, .
Distilled water	1000 c.c..
*p*H	7·0.

2. *Details of how tests were made*

a. *Reduction of nitrate*—The organism was inoculated in duplicate in tubes of nitrate broth and incubated at 30°C. Controls were also kept. These were tested occasionally with Greiss Ilosway's reagent for the presence of nitrite.

b. *Indol production*—Indol was tested in peptone water culture after an interval of 2 to 10 days with Ehrlich's reagent. (Para-dimethylamidobenzaldehyde solution and potassium persulphate solution).

c. *Production of H_2S*—Lead acetate agar was inoculated in duplicate with the organism and incubated at 30°C. with two control tubes; slight blackening of the inoculated tube showed the production of H_2S.

d. *Hydrolysis of starch*—Peptone broth containing 0·2 per cent soluble starch was employed for the purpose. A number of tubes of this medium were inoculated and kept under observation for a period of four weeks, and occasionally tested with iodine solution.

From the above recorded morphological and physiological study the organism apparently belongs to the family Bacillaceae, genus *Bacillus* and is mesophilic. It appears to belong to the *Bacillus subtilis* group but the cultural characteristics do not agree completely with any of the known species.

Hence a new species name *Bacillus fructodestruens* is proposed formally.

Bacillus fructodestruens (Madhok and Fazal-ud-Din) sp. nov.

Rods :	0·75-1·0 × 1·25-2·5 microns, occurring singly, motile with peritrichic flagella
Spores :	Central, ovoid, 0·75 × 1·2 microns, not bulging the sporangium
Gram stain :	Positive
Agar colonies :	Creamy white, raised, shining amaeoboid or branching, crenate margin. Roundish in thick plates
Agar slant :	Growth creamy white, shining, spreading at the bottom
Gelatine plate	Colonies circular, growth whitish, liquefaction
Gelatine stab :	Stab visible by whitish growth along it. Liquefaction, crateriform
Broth :	Slightly turbid. Thin pellicle, coherent
Potato :	Growth, brownish, spreading, shining with blackening of the substrate
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Indol not formed

Nitrate not reduced

Starch not hydrolyzed
Slight H_2S production
Acid from sucrose, dextrose, mannite, arabinose and glycerol
No acid from lactose, maltose, dulcitol and dextrin
No gas from carbohydrate broths
Ammonia produced from peptone
Optimum temperature 40°C. Growth limits 10° to 55°C.
Vegetative cells not killed at 70°C. for 10 minutes
Spores survive half an hour at boiling temperature
Strict aerobe
Source : Isolated from diseased tomato fruits
Habitat : Not studied

Bacterial soft rot of tomato has previously been recorded by Brierley [1928] as caused by artificial infection with *B. phytophthorus* and *B. aroideae*, now named *Erwinia phytophthora Appel*, and *Erwinia aroideae* Townsend, and classed in *Entrobacteriaceae* Rahn [Bergey 1939]. Brown [1926] has reported the production of stem-end and centre rot of tomato by artificial infection with six different non-sporing bacteria, viz. *Bact. malva cearum* EFS., *Bact. marginale* Brown, *Bact. campestre* EFS., *Bact. tumefaciens* Smith and Townsend ; *Bact. savastanoi* EFS., and *Bact. viridilividum* Brown. Both the workers, however, failed to produce the disease with any spore forming organism.

Pathogenesis

Having established that the spore forming organism isolated by us was capable of causing soft rot in healthy fruits, it was considered desirable to try infection trials on fruits actually borne on the plants.

The first trial was made at the end of January when fruits on two plants grown in pots were infected with the causative organisms with gentle needle pricks. No signs of the disease appeared even after three weeks. The trials were repeated in June when the organism successfully produced the infection which appeared in the form of brownish lesions after two days. These lesions became dark brown and wrinkled after five days.

This established the fact that the organism is a positive parasite but that it works only in the summer season when the surrounding temperature is high.

Note

It is generally believed that spore bearing bacteria do not cause plant diseases. In view of this the culture of the causative organism in this case was subjected to the following treatments to ensure its purity:

Repeated platings and reisolations of the culture were done. Two loopfuls of this selected sporing culture were inoculated in 10 c.c. of sterile water contained in a test tube. The inoculum was dispersed by gently rotating the tube in the palms of hands. Every precaution was taken both during inoculation and shaking of the inoculum to avoid contaminating the empty portion of the tube.

The inoculated tube was immersed in water-bath up to the plugged portion and the water brought to boil. After 10 minutes exposure at boiling temperature the culture was plated on nutrient agar and the organism reisolated from a characteristic plate colony. This culture when used for infection trials was found to be as virulent as the mother culture tried before. It developed spores on keeping.

The presence of any non-spore forming organism in this culture cannot be suspected after such a drastic heat treatment. This establishes the fact that the causal organism in this case is a spore forming bacillus.

Control

No attempts were made to study control measures that would check the progress of the disease because the pathogen is so virulent and the fruit so perishable that there is very little chance of recovery. The fruit once infected shows signs of the rot in two days and is totally mashed up within six days. Since the disease is only found on the fruit and on no other part of the plant, it is likely that the infection occurs in wounds caused by insects.

Summary

A soft rot of tomato fruits caused by a spore forming organism has been recorded. The disease appears in the form of an underskin rot which spreads rapidly and in four to six days the fruit is pulpy and mashed up. Morphological and cultural characteristics of the causative organism have been studied. The organism is a virulent pathogen and works best at high temperatures, viz. 98°-104°F.

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AVAILABILITY OF PHOSPHATES IN ALKALINE AND CALCAREOUS SOILS

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ONE of the main problems that confronts the agricultural chemist is the estimation of the requirements of a given soil for specific plant food materials. For various reasons even the most modern methods adopted for soil analyses fail to give in many cases the requisite information. Hence, from time to time, attempts have been made to attack the problem indirectly, and use the living plant as an analytical agent [Neubaner, 1925 ; Hardy, Hanschell and Amoroso-Centend, 1938]. The method consists in taking a particular plant and growing it on a given soil under controlled conditions, and then determine in its ash content the proportions of various mineral constituents including such plant food materials as nitrogen, potash and phosphoric acid. Any deviations from the normal in these proportions may then be taken as indicating deficiency or excess of the same constituent in the soil, and therefore, the need or otherwise of specific manuring in that direction. From this point of view, a number of investigations on the availability of phosphate in *bari* soil (alkaline soil) under controlled conditions have been carried out and the results are reported in this paper.

It has been stated elsewhere [Singh and Nijhawan, 1932] that the infertility of *bari* soil is mainly due to a deficiency of exchangeable calcium, which can be made good with the help of soluble calcium salts. It has also been observed [Singh and Nijhawan, 1936] that the physical properties of *bari* soil adverse to plant growth are greatly modified when the exchangeable calcium of the soil attains a value of 5·0 m.e. or more. Therefore, the low yields of wheat grain in the data already reported and reproduced below (Table I) for the sake of convenience could not be ascribed to either a deficiency of exchangeable calcium or any adverse physical conditions, but due to lack of some important plant food material.

TABLE I

Yield of wheat in lb. from plots treated with calcium salts

—	1929-30		1930-31		1931-32		1932-33		1933-34	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Calcium chloride at two tons per acre from 1927-30	288	699	767	1206	1160	1975	1438	2178	1439	3000
Gypsum at two tons per acre from 1927-30	226	411	267	417	769	1327	1726	2589	1336	2734

Farmyard manure was applied in the year 1930 for the first time at the rate of 15 tons per acre.

From the above data it will be seen that with the application of farmyard manure in 1930, there was a sudden increase in the yield of wheat crop, amounting to almost double of what was obtained in 1929. Subsequent applications of manure further improved the yields and a maximum was attained in 1932-33. The ratio of straw to grain decreased with the applications of farmyard manure, and it occurred to the authors that increased yields of grain might be due to an increased availability of phosphates rather than nitrogen. Breazeale and McGeorge [1932] observed that due to a deficiency of carbon dioxide in the calcareous soils nutritional disorders set in, and that an addition of manure to the black alkali soil evolved carbon dioxide which rendered more phosphate available to the crop. Therefore, in order to find out whether the application of calcium salts employed in the process of reclamation of *bari* soil with and without the addition of farmyard manure affected the availability of phosphoric acid, the following experiments in pots were arranged :

Experiment No. 1

The experiment was carried out on *bari* soil from the Montgomery Agricultural Station where the field experiments referred to above had been in progress for a number of years. A composite sample of the soil on analysis gave the following results (Table II) :

Table II

Analysis of 'bari' soil

(Per cent on air-dry soil)

I *Mechanical analysis*

Clay	Silt	Fine sand	Coarse sand	*Kankar*
20·16	37·23	41·11	0·72	0·35

II *Chemical analysis*

Insoluble residue	Soluble silica	Fe_2O_3	Al_2O_3	CaO	MgO	P_2O_5	K_2O	Na_2O	Organic matter	Nitrogen
76·85	0·11	4·93	8·54	3·08	1·45	0·25	1·16	0·87	0·28	0·03

III *Available analysis*

Phosphorus (P_2O_5)	Potassium (K_2O)
0·10	0·09

IV *Exchangeable bases* (Milligram-equivalents)

Calcium as Cs	Magnesium as Mg	Sodium as Na	Potassium as K
1·53	1·30	9·39	1·05

From the finely powdered and properly mixed bulk sample 12,000 gm. of the soil were put in each pot. Thus, altogether 12 pots were prepared, each treatment being given in duplicate. After thoroughly leaching the soil to remove its excess of soluble salts, the following treatments were given :

Treatments

I. Calcium chloride with and without farmyard manure . . . . 6·66 gm. per pot

II. Gypsum with and without F. Y. M. (calculated on basis of calcium in $CaCl_2$) . . . 10·32 gm. per pot

III. Normal soil with and without F. Y. M.

Farmyard manure was added at the rate of 15 tons per acre. Before sowing wheat soil samples were obtained, and available phosphorus determined in them by Dyer's citric acid method [1894] and Das' potassium carbonate method [1926]. The results of analysis are reported in Table III.

TABLE III

Availability of phosphates with citric acid and potassium carbonate methods

Description	Name of method	P_2O_5 as percentage on air-dry soil
1 *Bari* soil untreated	(*a*) Citric acid	0·1234
	(*b*) K_2CO_3	0·0013
2 *Bari* soil treated with calcium chloride	(*a*) Citric acid	0·1252
	(*b*) K_2CO_3	0·0018
3 *Bari* soil treated with calcium chloride and farmyard manure	(*a*) Citric acid	0·1399
	(*b*) K_2CO_3	0·0061
4 Normal soil	(*a*) Citric acid	0·0345
	(*b*) K_2CO_3	0·0014

From the data presented in Table III it will be seen that by both the methods the *bari* soil appeared to be rich in available phosphorus, which is even more than that in the normal soil. On treatment with calcium salts and farmyard manure the phosphate content increased slightly. Similar results were obtained with potassium carbonate method as in the case of citric acid. Thus, it will be observed that according to chemical methods of soil analysis the *bari* soil does not appear to be deficient in available P_2O_5, but on the other hand, the phosphate content by Dyer's method is as high as hydrochloric acid-soluble phosphate present in some of the fertile soils of the Punjab. For the sake of comparison the results of acid-soluble P_2O_5 from some of the good soils in the Punjab are given in Table IV.

TABLE IV

Total and available phosphates in Punjab soils

(Percentage on air-dry soil)

(P_2O_5)

Description	Hydrochloric acid-soluble	Citric acid-soluble
1 *Bari* soil	0·256	0·100
2 Lyallpur (Agricultural Farm)	0·196	0·054
3 Gujranwala (Kala Shah Kaku)	0·174	0·059
4 Kangra (Baijnath)	0·079	0·029
5 Montgomery	0·263	0·063
6 Rohtak	0·118	0·029

Hydrochloric acid-soluble as well as citric acid-soluble phosphorus is greater in the *bari* soil than in the normal soils. These results clearly show that the chemical methods of soil analysis in the case of alkaline soil do not

give a true indication of the availability of phosphorus, but give abnormally high values. On maturity the entire wheat crop was removed, dried, weighed, ashed and analysed for various mineral constituents according to tentative and official methods of the Association of Official Agricultural Chemists. The results are reported in Table V.

TABLE V

Crop analysis : yield and composition of wheat crop affected by calcium salts and F. Y. M.

Treatments	Iron Fe_2O_3	Calcium CaO	Magnesium MgO	Phosphate P_2O_5	Potassium K_2O	Yield per pot
I Set—						
Calcium chloride . .	0·1697	1·99	0·280	0·0911	1·84	10·3
Gypsum	0·0800	1·77	0·390	0·1359	1·90	68·4
Normal soil . . .	0·0893	0·94	0·385	0·2069	2·66	10·36
II Set—						
Calcium chloride and F. Y. M.	0·1699	0·83	0·235	0·5037	1·78	17·7
Gypsum and F. Y. M. .	0·1954	0·57	0·285	0·3503	1·38	14·3
Normal soil and F. Y. M. .	0·2194	0·47	0·296	0·4817	2·59	11·2

A reference to Table V shows that in the first set, where chemicals alone are employed, the amount of P_2O_5 removed in the case of soil treated with calcium salts is much less than in the case of normal soil. The amount of K and Mg removed is also less, but the variation is not of the same order. On the other hand, the amount of Ca removed is much greater than that of the normal soil. In the second set, with the addition of F. Y. M., the amount of P_2O_5 removed in all cases is much greater than in the first set, the percentage increase being greater in the case of soils treated with calcium salts. The same is the case with iron which also records a great increase with the addition of F. Y. M. Calcium, on the other hand, shows a tremendous decrease, while Mg and K only record a slight decrease. These results also show that the crop removed from calcium chloride-treated soil contains greater amount of P_2O_5 and calcium than that removed from gypsum-treated soil. These findings are in accordance with the yield data which are greater in case of calcium chloride pots than those treated with gypsum.

EXPERIMENT No. 2

The results from the first experiment suggested that the uptake of calcium and phosphates, and more especially the latter as revealed by the crop analyses, depended on the nature of calcium salts used in the reclamation process. The lower yield in case of gypsum when F. Y. M. is added may be due to less availability of phosphorus for the growth of plants. Gypsum being a comparatively cheap chemical is likely to find more use for the reclamation of *bari* soil, and it seemed necessary that its effect on the availability of phosphorus which appeared to operate as a limiting factor in the crop production in this type of soil, should be investigated. With this end in view, a pot experiment was arranged and both the calcium salts were added in increasing doses. Calcium chloride was added at the rate of 0·5, 1·0, 2·0, 4·5, and 7·5 tons per acre and gypsum was added in equivalent amounts. Farmyard manure

was added in each pot at the rate of 15 tons per acre. Each treatment was arranged in duplicate, and wheat crop sown. The ash analyses of the crop removed from these pots are given in Table VI.

TABLE VI

Crop analysis : composition and yield of wheat crop affected by varying doses of calcium salts

Treatments	Iron Fe_2O_3	Calcium CaO	Magnesium MgO	Phosphate P_2O_5	Potassium K_2O	Nitrogen N	Yield in gm. per pot
1 Calcium chloride at ½ ton per acre	0·2277	0·4686	0·3535	0·5217	2·65	...	5·8
2 Gypsum at 0·77 ton per acre	0·1204	0·3623	0·3451	0·3036	1·75	...	5·6
3 Calcium chloride at 1 ton per acre	0·2014	0·5116	0·2877	0·6288	2·39	1·47	7·2
4 Gypsum at 1·55 ton per acre	...	0·2970	0·3964	0·5345	2·33	1·39	3·0
5 Calcium chloride at 2 tons per acre	0·3023	0·4069	0·3284	0·5967	2·95	1·33	7·3
6 Gypsum at 3·1 tons per acre	0·3895	0·4512	0·3623	0·5662	3·16	1·36	5·3
7 Calcium chloride at 4·5 tons per acre	0·3134	0·6347	0·3814	0·7097	3·74	...	6·4
8 Gypsum at 7·5 tons per acre	0·3039	0·3868	0·2681	0·5416	2·32	1·36	7·6
9 Calcium chloride at 7·5 tons per acre	0·2321	0·5371	0·2559	0·6580	2·77	1·39	8·5
10 Gypsum at 11·66 tons per acre	0·2633	0·6096	0·3741	0·5429	2·78	1·33	8·1

Up to a certain level which is attained when gypsum and calcium chloride are applied at the rate of 3·1 and 4·5 tons per acre respectively, there is an increase in the mineral matter of all the ingredients with increasing doses of calcium salts, but after that level further increase in the doses of calcium salts bring about generally a decrease in the mineral matter removed. Further, it is observed, that more calcium and P_2O_5 is removed by plants grown in the calcium chloride-treated soil than from the gypsum-treated soil, but the increase is more marked in the case of P_2O_5 than in the case of calcium. Maximum amount of P_2O_5 removed was 0·7097 per cent by plants grown on calcium chloride-treated soil, while the maximum amount removed by the plants from the gypsum-treated soil was only 0·5662 per cent. These results again show that the treatment of *bari* soil with calcium salts renders more P_2O_5 available, the increase in the case of calcium chloride being greater than in the case of gypsum. Total nitrogen was also determined in the crop, but the results do not show any effect of the chemicals on the amount of nitrogen removed by the crop.

EXPERIMENT No. 3

While studying the effect of different cations saturating the soil exchange complex on the physical properties of *bari* soil, the authors [1936] observed that such soils were able to support a crop of wheat if sodium of the exchange complex was replaced by magnesium, manganese or potassium. The soil in its original condition contains 3·08 per cent of calcium oxide which is almost entirely present as calcium carbonate, and if this calcium could be made to react with the soil, it will replace sodium from the exchange complex and thus bring about an improvement of the soil. While preparing ammonium

clays by leaching the soil with ammonium salt solutions the authors [1936] observed that only half the sodium was replaced with ammonium ions, the remaining half being replaced by calcium ions. The reason appeared to be that calcium carbonate is soluble in ammonium salts, and in that manner is able to react with the sodium of the exchange complex. Similarly, calcium carbonate can be rendered soluble by treating the soil with acids thereby utilizing calcium for the exchange reaction. In order to determine the effect of other salts and acid treatment tried in the reclamation of *bari* soil on the availability of phosphate in this soil, an experiment with the following treatments was arranged :

1 Calcium chloride at 4·5 tons per acre with and without farmyard manure
2 Magnesium nitrate with and without farmyard manure
3 Manganese chloride with and without farmyard manure
4 Potassium nitrate with and without farmyard manure
5 Ammonium sulphate at 820 lb. per acre with and without farmyard manure
6 Hydrochloric acid just sufficient to liberate 0·1 per cent of calcium with and without farmyard manure.

Magnesium nitrate, manganese chloride and potassium nitrate were added in equivalent amount to calcium chloride at the rate of 4·5 tons per acre. The pots filled with 12,000 gm. of the soil were flooded and washed to remove the excess of water-soluble salts. After the treatments the pots were left over for a period of five months during which interval they were occasionally watered and stirred. Farmyard manure was added at the end of this period and crop sown a fortnight later. Results of crop analyses and yield data are given in Table VII.

TABLE VII

Crop analysis: composition and yield of wheat crop as affected by treatment with various salts (with and without F. Y. M.)

Treatments	Iron Fe_2O_3	Calcium CaO	Magnesium MgO	Phosphates P_2O_5	Potassium K_2O	Nitrogen N	Yield in gm. per pot
1 Calcium chloride without F. Y. M.	0·445	0·486	0·241	0·102	1·012	...	3·4
2 Calcium chloride with F. Y. M.	0·338	0·402	0·242	0·282	0·544	1·39	6·9
3 Magnesium nitrate without F. Y. M.	0·398	0·529	0·595	0·167	2·112	...	4·4
4 Magnesium Nitrate with F. Y. M.	0·347	0·408	0·627	0·280	1·832	...	6·10
5 Manganese chloride without F. Y. M.	0·360	0·604	0·319	0·164	1·110	...	2·3
6 Manganese chloride with F. Y. M.	0·380	0·650	0·391	0·548	2·797	...	6·0
7 Ammonium sulphate at 10 md. per acre without F. Y. M.	0·296	0·659	0·316	0·191	1·579	1·73	3·9
8 Ammonium sulphate at 10 md. per acre with F. Y. M.	0·232	0·441	0·310	0·405	2·849	1·52	8·1
9 Potassium nitrate without F. Y. M.	0·868	1·340	0·434	0·259	13·630	...	1·4
10 Potassium nitrate with F. Y. M.	0·620	0·764	0·362	0·340	5·260	...	3·5
11 Hydrochloric acid without F. Y. M.	0·207	0·609	0·320	0·209	1·545	...	4·8
12 Hydrochloric acid with F. Y. M.	0·201	0·388	0·321	0·296	1·813	1·42	8·3

The results obtained show that though the availability of phosphates depends on the nature of the salts applied, yet the application of farmyard manure in all the cases increased the amount of phosphate in the crop. With increase in phosphate, there was a corresponding increase in the yield of the crop, and the yields from the pots treated with farmyard manure were nearly double of those which did not receive any application of it.

The application of nitrogenous fertilizers alone in no way increased the yields. Nitrogen removed by the crop from the soil-treated with ammonium sulphate alone was undoubtedly more but it had no effect on the yield of the crop. The yields from the pots treated with ammonium sulphate and potassium nitrate were not more than those from the pots under other treatments, but these became more than double by the application of farmyard manure. Phosphates were removed comparatively in large amounts from all the pots treated with other salts than those treated with calcium salts.

With the application of farmyard manure though the amount of phosphates in the crop increased yet there was a decrease in all other minerals, decrease being more in the case of iron and calcium than magnesium, which slightly decreased or remained more or less constant. The behaviour of potassium was however different. Potassium in the crop removed from the pots treated with calcium, magnesium and potassium salts showed a decrease, but that removed from the pots treated with manganese chloride, ammonium sulphate and hydrochloric acid showed a definite increase, the increase being more in the crop got from the pots treated with the first two salts than those treated with hydrochloric acid.

Crops removed a comparatively larger amount of the salt with which the soil is treated, except in the case of soil treated with calcium salts where the amount of calcium removed was more or less the same or even less than that removed by the crops grown in the soil treated with other salts. Potassium was removed in very large quantities (13·630 per cent), but its amount greatly decreased (5·24) when farmyard manure was added in addition to the potassium salt. Thus, the luxury consumption of potassium manures can be greatly decreased by the addition of farmyard manure.

Conclusions

1. Chemical methods do not give correct information regarding the availability of phosphorus in alkaline calcareous soils. Acidic extracting agent like citric acid used in Dyer's method yields large amount of phosphate. Phosphate thus found is much higher than usually found in calcareous soils.

2. Phosphate removed by wheat crop from an alkaline soil reclaimed by the application of calcium salts is much less than by the crop grown on a normal soil.

3. Application of farmyard manure to such a soil increases the absorption of phosphate by the crop, which becomes as high as in a crop raised on a normal soil.

4. Crop removed from a calcium chloride-treated soil contains more phosphorus and calcium than the crop grown on a gypsum-treated soil.

5. With increasing doses of calcium salts, there is an increase in the amount of phosphate removed by the crop, increase being more in the case of calcium chloride-treated soil than in the case of gypsum-treated one. Maximum

amount of phosphate removed by the crop from the soil treated with calcium chloride and gypsum was 0·7097 and 0·5662 per cent respectively.

6. Salts other than calcium which may be used for the reclamation of alkaline soils increase the amount of phosphates removed by the crop, but its quantity is much less than that found in a normal wheat crop. On the other hand, application of farmyard manure in addition to these treatments brings about a great increase in the phosphorus content of the crop.

7. Application of nitrogenous fertilizers does not increase the yield, but when farmyard manure is also added, the yields are doubled. Application of farmyard manure, however, does not increase the nitrogen content of the crop.

8. The nature of cations in the exchange complex affects the availability of phosphorus. A calcium soil possesses less available phosphorus than soils containing other cations.

9. Plants remove in larger amounts the cation with which the soil complex is saturated, excepting calcium, which is removed more or less in the same quantity as from a soil saturated with other cations. Potassium is removed in much larger quantity as compared to other cations.

10. With the application of farmyard manure though there is increase in the amount of phosphate removed there is a decrease in other minerals such as calcium, magnesium and iron.

11. When farmyard manure is added to soils treated with salts of potassium, magnesium and calcium, the potassium removed by the crop from these soils decreases.

12. In the case of alkaline calcareous soils crop analyses give better indication of the availability of minerals, especially phosphorus.

Summary

The results corroborate the findings of other workers that the chemical methods of analyses do not give correct information regarding the availability of phosphates in alkaline calcareous soils. Crop analyses give better results.

The availability of phosphates and other minerals as affected by the different salts with and without F. Y. M. in the reclamation of *bari* soil has also been investigated.

With the application of calcium chloride the availability of phosphorus in the presence of farmyard manure is increased.

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FRACTIONATION OF SOIL PHOSPHORUS

II. CHEMICAL NATURE OF THE PHOSPHORUS FRACTIONS

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In the work reported previously [Ghani, 1942], $N/2$ acetic acid, $N/4$ sodium hydroxide and $2N$ sulphuric acid were used as extractants in a method of fractionation of soil phosphorus and the conditions of extraction were critically examined. The inorganic phosphorus fractions dissolved by acetic acid, sodium hydroxide and sulphuric acid in succession were tentatively supposed to be non-apatitic calcium phosphates, iron and aluminium phosphates and apatite phosphates respectively. But before any hard and fast conclusion can be drawn regarding the chemical nature of the different fractions it is necessary that the solubility of known phosphorus compounds in these solvents should be known and the solubility determinations should be made under the same conditions as are adopted in the fractionation. Until accurate and independent methods for the determination of the individual phosphorus fractions in soil are known this mode of attack will remain to be the only way in deciding the point in question.

Solubility study of inorganic phosphorus compounds

Many attempts have been made in the past to deduce the probable nature of the acid and alkali soluble phosphates of soil by studying the solubility of common phosphatic materials in different solvents and in solutions having different *p*H values. Fraps [1911] found that ammonia dissolved phosphoric acid from phosphates of iron and aluminium more readily than from phosphates of lime. He believed that ammonia extracted from soil the organic phosphorus and iron and aluminium phosphates. Gaarder [1930] studied the solubility of iron, aluminium, calcium and magnesium phosphates in solutions of various *p*H values. He found that ferric phosphate had its point of minimum solubility near *p*H 2. With still more acid conditions there was complete solubility while a change towards the alkaline side resulted in the hydrolysis of iron phosphates. Aluminium phosphate reacted in much the same way, the point of minimum solubility being at about *p*H 4. Calcium phosphate was precipitated between *p*H 6 and *p*H 7 and did not hydrolyse at higher *p*H values. The work of McGeorge [1935] also showed a similar relation between *p*H and solubility.

Williams [1937] found that the mineral calcium phosphates had a very low solubility and the iron and aluminium phosphate minerals a high solubility

in 5 per cent sodium hydroxide. Dean [1938] got similar results with both sodium hydroxide and sodium carbonate. Both the authors extracted the materials by digesting at 100°C.

Experimental

The solubility of mono-, di- and tricalcium phosphates, apatite, ferric phosphate (basic and normal) and aluminium phosphate each in $N/2$ acetic acid, $N/4$ sodium hydroxide and $2N$ sulphuric acid were determined. The extractions were done by shaking 10 mg. of the substance at room temperature for two hours in a mechanical shaker with appropriate volume of each of the solvents. Phosphorus determinations in the extracts were made by the colorimetric method of Deniges as improved by Truog and Meyer [1929]. The results showing the solubility in mg. P_2O_5 as well as in per cent of the total P_2O_5 appear in Table I.

Table I

Solubilities of known phosphorus compounds in acetic acid, sodium hydroxide and sulphuric acid

Substances	Calcium phosphate (monobasic)	Calcium phosphate (dibasic)	Calcium phosphate (tribasic)	Apatite	Iron phosphate (normal)	Iron phosphate (basic)	Aluminium phosphate
Mg. P_2O_5 taken (10 Mg. substance)	5·63	4·61	4·58	3·80	4·77	2·00	5·82
Mg. P_2O_5 sol. in acetic acid (250 c.c.)	5·62	4·61	4·22	2·40	0·30	0·24	2·8
Per cent P_2O_5 soluble . .	100	100	92	63	6	12	48
Mg. P_2O_5 sol. in $N/4$ NaOH (500 c.c.)	4·00	1·32	0·12	Trace	4·0	1·6	3·8
Per cent P_2O_5 soluble . .	71	29	3	...	84	80	65
Mg. P_2O_5 sol. in $2N$ H_2SO_4 (250 c.c.)	5·74	4·60	4·60	3·40	3·90	2·00	4·40
Per cent P_2O_5 soluble . .	100	100	100	90	82	100	76

In $N/2$ acetic acid both mono- and dicalcium phosphates are completely soluble while tricalcium phosphate is slightly less soluble. About two-third of the apatite phosphorus has been dissolved in it. This high solubility of apatite phosphorus in dilute acetic acid may be due to the fact that the apatite minerals usually contain some soluble tricalcium phosphate. This is more probable because the residual phosphorus in the sample was sparingly soluble in $N/2$ acetic acid, and could not be dissolved by repeating the extraction several times. Solubility of the two iron phosphates is extremely low in acetic acid ; it comes to about 0·1 mg. P_2O_5 per 100 c.c. of the solvent used. Aluminium phosphate is, on the other hand, more soluble than iron phosphates. Gaarder [1930] pointed out that the minimum solubility of aluminium phosphate was at a *p*H of 4 but the *p*H of the acetic acid used here was near about 3 and hence latter may dissolve more of the phosphates. But again McGeorge [1935] comparing the solubility of iron and aluminium phosphates found that 4 was not the optimum *p*H for aluminium phosphate and that it was much more soluble than iron phosphate at that *p*H. On the whole it would thus seem that acetic acid will extract from soil mainly mono- and

dicalcium phosphates and non-apatitic tricalcium phosphates whereas other types of soil phosphorus would mostly remain in the residue. Even if any other phosphorus compound such as aluminium phosphate be dissolved, the amount would be comparatively small.

It is further seen that the solubility of the monobasic calcium phosphate is about 71 per cent in sodium hydroxide and that it rapidly falls off as the basicity of the substance increases. Ultimately the solubility is almost nil in the case of the mineral. On the other hand, the phosphates of iron and aluminium are highly soluble though the aluminium compound is comparatively less soluble. This would show that if the alkali extraction of the soil is done after an acetic acid extraction, the alkali will dissolve iron and aluminium phosphates only (besides organic phosphorus). This is because mono-, di- and tricalcium phosphates had already been removed from the soil by the acid pretreatment and apatite phosphorus is insoluble in alkali. In $2N$ sulphuric acid all the substances except aluminium phosphate are highly soluble. The solubility of apatite is about 90 per cent and it may be assumed that the phosphates of apatite nature that remain unaffected by the previous acid and alkali extractions would be dissolved by $2N$ sulphuric acid in the last treatment. The descending order of solubility of the calcium phosphates with increasing alkalinity or decreasing acidity shows the completely differrent behaviour of iron and aluminium phosphates. They first decrease reaching a minimum and then increase with increase in pH.

From what has been said above it would seem that alternate extraction with acetic acid, sodium hydroxide and sulphuric acid may be made a reasonable basis for the fractionation of the soil phosphorus into groups of known substances. To test the point further, mixtures of soil and known phosphorus compounds were fractionated by the method already described by one of the authors [Ghani, 1942]. Such a fractionation will show the extent of recovery of the various substances added and the fractions in which they are recovered and would therefore give valuable information regarding the validity of fractionation.

Fractionation of mixtures of soil and known phosphatic compounds

Two soils were selected one of which was nearly neutral in reaction (pH 7·3) and the other highly acid (pH 4·5). If there be any subsidiary reaction between the added phosphorus and the other soil constituents, it would be reflected in the behaviour of the two soils having different pH.

One gram samples of the two soils were thoroughly mixed with 10 mg. of the following substances: mono-, di- and tricalcium phosphates, apatite, ferric phosphate and aluminium phosphate. The mixtures were moistened with water to cause more intimate mixing of the substance and the soil, air dried after a few hours and then fractionated. A control sample without any phosphatic material in it was similarly treated and fractionated exactly in the same way. The results of the fractionation are shown in Table II.

The column 'added P_2O_5 recovered' has been obtained by subtracting the total of the control from the sum of the three fractions determined in the mixtures.

Taking into consideration the inevitable errors in adding up so many fractions, it appears that the recovery of the added phosphorus is almost 100

per cent in all the mixtures excepting the one containing aluminium phosphate. This is true for both the soils. Aluminium phosphate behaves rather abnormally as the whole of its phosphorus cannot be accounted for by the three fractions. By a reference to Table I it is seen that its solubility in sodium hydroxide as well as in sulphuric acid is much lower than that of the other substances, which means that a part of its phosphorus is present in a highly insoluble form. If, however, the recovery is expressed as per cent of the soluble phosphorus added, instead of the total phosphorus added, it amounts to about 92 and 97 per cent in the two soils.

TABLE II

Fractionation of a mixture of soil and various inorganic phosphorus compounds

Substance mixed with soil	P_2O_5 added (mg.)	Acetic acid sol. P_2O_5 (mg.)	Alk. sol. inorg. P_2O_5 (mg.)	Sulphuric acid sol. P_2O_5 (mg.)	Total P_2O_5 dissolved (mg.)	Added P_2O_5 recovered (mg.)	Per cent P_2O_5 recovered
Soil—Jessore, pH 7·3							
No substance	*nil*	1·16	0·29	0·52	1·97	...	...
Calcium phosphate (monobasic)	5·63	6·40	0·56	0·50	7·46	5·49	98
Calcium phosphate (dibasic)	4·61	5·44	0·56	0·50	6·5	4·53	98
Calcium phosphate (tribasic)	4·58	5·25	0·64	0·63	6·52	4·55	99
Apatite	3·80	2·69	0·69	2·40	5·78	3·81	100
Iron phosphate (normal)	4·77	1·58	4·00	1·00	6·58	4·61	97
Aluminium phosphate	5·82	3·60	0·90	1·44	5·94	3·97	68
Soil—Karimganj, pH 4·5							
No substance	*nil*	0·01	0·18	0·08	0·27	...	...
Calcium phosphate (monobasic)	5·63	5·37	0·72	0·18	6·27	6·00	100
Calcium phosphate (dibasic)	4·61	4·54	0·64	0·16	5·34	5·07	100
Calcium phosphate (tribasic)	4·58	4·00	0·64	0·17	4·81	4·54	99
Apatite	3·80	2·06	0·56	1·50	4·12	3·85	100
Iron phosphate (normal)	4·77	0·34	3·36	0·72	4·42	4·15	87
Aluminium phosphate	5·82	1·86	2·40	0·40	4·66	4·39	75

APPORTIONMENT OF THE ADDED PHOSPHORUS IN VARIOUS FRACTIONS

Percentage recovery of the added phosphorus in the different fractions is shown in Table III from which it will be seen that about 93 per cent of added mono-, di- and tricalcium phosphates have been recovered along with the acetic acid soluble fraction of the soil phosphorus. The major part of the apatite phosphorus has distributed itself in the strong acid soluble fraction. If, as pointed out before, the high acetic acid solubility of apatite phosphorus is ascribed to the presence of tricalcium phosphate and allowance made for it then the recovery of the apatite phosphorus in sulphuric acid comes to about 83 per cent. Ferric phosphate, on the other hand, has been recovered mostly with the alkali soluble fraction of the soil phosphorus. As before, aluminium phosphate does not give agreeable results. The above observation apply equally well to both the soils. The percentage recovery of the various subs-

tances in the fractionation is nearly the same as the percentage solubility in the solvents used.

TABLE III

Apportionment of the added P_2O_5 in the various fractions

Substance	......	P_2O_5 added	P_2O_5 recovered by acetic acid soln.	P_2O_5 recovered by NaOH soln.	P_2O_5 recovered by H_2SO_4 soln.
Jessore soil.					
Monocalcium phosphate	Mg. recovered	5·63	5·24	0·27	...
	Per cent recovered	...	93	5	...
Dicalcium phosphate	Mg. recovered	4·61	4·28	0·27	...
	Per cent recovered	...	93	6	...
Tricalcium phosphate	Mg. recovered	4·58	4·09	0·35	0·11
	Per cent recovered	...	89	8	2
Apatite	Mg. recovered	3·80	1·53	0·40	1·88
	Per cent recovered	...	40	11	49
Ferric phosphate	Mg. recovered	4·77	0·42	3·71	0·48
	Per cent recovered	...	9	78	10
Aluminium phosphate	Mg. recovered	5·82	2·44	0·61	0·92
	Per cent recovered	...	42	10	16
Karimganj soil					
Monocalcium phosphate	Mg. recovered	5·63	5·36	0·54	0·10
	Per cent recovered	...	95	10	2
Dicalcium phosphate	Mg. recovered	4·61	4·53	0·46	0·10
	Per cent recovered	...	98	10	2
Tricalcium phosphate	Mg. recovered	4·58	3·99	0·46	0·09
	Per cent recovered	...	87	10	2
Apatite	Mg. recovered	3·80	2·05	0·38	1·42
	Per cent recovered	...	54	10	37
Ferric phosphate	Mg. recovered	4·77	0·33	3·18	0·64
	Per cent recovered	...	7	67	13
Aluminium phosphate	Mg. recovered	5·82	1·85	2·22	0·32
	Per cent recovered	...	32	38	6

The evidence adduced above, though not free from minor irregularities, would, in general, lend support to the principle of the fractionation adopted. That is, without committing any serious error, the acetic acid soluble fraction can be taken to represent mono-, di- and non-apatite tricalcium phosphate of the soil, the alkali soluble inorganic fraction to represent iron phosphate and a part of aluminium phosphate while the sulphuric acid soluble fraction would represent phosphorus of apatite nature. The phosphorus that would be left in the soil after these combined acid and alkali extractions cannot certainly include the above-mentioned classes in any appreciable amount.

Summary

With a view to deducing the chemical nature of the phosphorus fractions extracted from soil by $N/2$ acetic acid, $N/4$ sodium hydroxide and $2N$ sulphuric acid, solubilities of phosphorus compounds in the above solvents have been studied.

The solubility study shows that (*a*) in acetic acid calcium phosphates are highly soluble, (*b*) in sodium hydroxide the phosphates of iron and aluminium are highly soluble whereas tricalcium phosphate and apatite are highly insoluble, and (*c*) in sulphuric acid all the compounds are highly soluble.

Fractionation of a mixture of soil and various phosphorus compounds shows that most of the mono-, di- and tricalcium phosphates are recovered with the acetic acid soluble fraction and that ferric phosphate is mostly recovered with the alkali soluble fraction.

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STEM-ROT DISEASE OF JUTE

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(With Plate V)

NO other single disease of jute (*Corchorus capsularis* and *Corchorus olitorius*) causes more damage, both to outturn and quality of fibre, than the stem-rot due to *Macrophomina Phaseoli* (Maubl.) Ashby [=*Rhizoctonia bataticola* (Taub.) Butler]. Shaw [1912] considered it to be a destructive disease of seedling jute and was of opinion that it was sporadic and occurred in an epidemic form only under certain conditions. Since then it has been found to be of widespread occurrence in Bengal and is reported to occur in Assam, Bihar and Orissa.

The fungus can attack the jute plant both in the seedling and the adult stage, leading to the formation of gaps in the field and reduction in yield. The jute crop is as a rule thickly planted so as to discourage branching and yields in consequence a superior fibre. When the disease is mild and the deaths are few in the crop, there is not much cause for anxiety ; but if the death rate is severe, large gaps may occur and the plants develop stems of uneven thickness which not only take a longer time to ret but produce a coarser fibre. With wider spacings, the plants are induced to branch, rendering them useless for fibre production.

In the adult stage the damage done is of a more serious nature. In addition to loss by deaths in plants that have not succumbed to the disease the stem usually splits and shreds. Such stems take 10 to 15 days more to ret and the fibre itself instead of being glossy, fine and white in appearance (Plate V, fig. 3) is coarse, brownish, weak and lacking in lustre, (Plate V, fig. 2) often with persistence of periderm (Plate V, fig. 4). The fibre from dead stems is uniformly dull, coarse and brittle, studded with the sclerotia of the fungus (Plate V, fig. 1).

SYMPTOMS

Seedlings

On the seedlings, the earliest symptoms manifest themselves either on the hypocotyl in the form of lesions near the collar and the node or on the cotyledonary leaves. They are in thin streaks and blackish-brown to black [Ridgway, 1912]. Under wet conditions the younger seedlings damp off but when conditions are dry and the seedlings have reached a three leaf-stage, they develop blight resulting in the shedding of the leaves and the death of the plants. Blight also occurs when the tender roots get infected. However, in many of the damped off and blighted plants the aerial parts are the first to be affected, the roots being subsequently invaded. On the cotyledonary leaves, the necrotic lesions are orange-citrine and roundish. As rotting of the leaves

and the hypocotyl proceeds, pycnidia are formed in abundance. Sclerotia are, however, formed in all the parts of seedlings.

Growing plants

Leaves. Buffy citrine necrotic lesions occur mainly along the apex and the margins of the leaves ultimately covering the entire leaf including the mid rib and the petiole. A majority of such leaves are shed. Sclerotia have never been observed on the affected leaves but numerous pycnidia cover the entire lamina and the petiole (Plate V, fig. 12). The pycnidial ostiole is generally on the upper surface of the leaf.

Stem. The primary lesions on the stem usually occur at the nodes as small, blackish-brown depressions, which later increase in size in both the directions (Plate V, fig. 6). The streaks vary in size from half an inch to nine inches (Plate V, fig. 7). Several lesions may coalesce and gradually girdle the stem. In such advanced cases, the plants wilt leaving bare dead stalks in the field with abundant pycnidia all over (Plate V, figs. 8 and 11).

Where the streaks run along the length of the stem without girdling it, the cortex gets shredded exposing the fibrous tissue. Adventitious roots may develop at the two ends of the streaks (Plate V, fig. 9) and such plants continue to grow but they break easily when strong wind blows. The plants always remain dwarfed and bushy.

In some vigorously growing plants the lesions may become localized due to cork formation. Such cankers are half to one inch long and dull greenish black in colour. A furrow may form if several such cankers coalesce (Plate V, fig. 10).

A microscopic examination of the infected stems shows the presence of the fungus in all the soft tissues, the epidermis and the cortex being the most affected. Where the infection is widespread the fungus spreads inwards invading the phloem parenchyma and the wide rays between the phloem wedges. It is also found in the central woody portion, the hyphae penetrating even the wood fibres. Pycnidia are usually embedded in the epidermis of the stem and sclerotia are found in the ray-cells and the softer tissues of the phloem and the xylem. In cankers, pycnidia and sclerotia occur sporadically.

Roots

In plants whose aerial parts are attacked, the roots very often are healthy. It is only after all the parts of such plants die, the infection extends to the roots. Sometimes, however, direct infection of roots occurs in which case the plants wilt. Such plants can easily be uprooted and their roots are found to have disintegrated. Attacked roots are invariably full of black sclerotia of the fungus.

Capsules

Discolourations on the capsules are found at all stages of growth. Infected capsules are liable to drop off or split; in the latter case the seeds invariably get infected. In some of the unsplit diseased capsules the seeds also may be diseased. Infected seeds are sayal brown, without any lustre and light in weight. Sclerotia are found within the capsule and on seeds. Pycnidia occur on the outer surface of the capsule and sporadically on the seeds. Mycelia and sclerotia of the fungus have been observed under the seed-coat and sometimes in the cotyledons.

The fungus

The morphological characters of the fungus have been well established by Sawada [1916] and Shaw [1924]. A similar fungus was isolated at Dacca Farm from all the affected parts. Monospore isolations from pycnidia found on leaves, stem and capsules and isolations of the sclerotia yielded the same fungus.

In order to make the sclerotial measurements comparable with those given by Haigh [1930], the fungus was cultured on maize meal agar medium prepared according to his formula. He reports that the sclerotia of C strains 'attain their maximum size in four to six weeks'. Consequently the cultures were allowed to grow for six weeks at room temperature which varied from 24° to 27°C. Two hundred sclerotia were measured and their diameters varied from 41 to 86 μ, the mean being 60 ± 0.8 μ. The sclerotia of the stem-rot fungus lie in the C group of Haigh.

Pycnidia from leaves and stems were separately collected and incubated in water at 32°C. till the spores were discharged. One hundred pycnospores were measured soon after their discharge. Pycnospores from leaves were comparatively bigger than those from the stems. The pycnospore measurements furnished in Table I compare well with those recorded by Ashby [1927] for *Macrophomina Phaseoli.*

TABLE I

Measurements of pycnospores

Workers	Source	Length in microns		Width in microns	
		Range	Mean	Range	Mean
Shaw [1924]	Jute stem	16—27	..	6—8	..
		17—29	..	6—8	..
		16—24	..	7—8	..
		20—27	..	7—9	..
		16—27	..	7—11	..
		16—24	..	8—11	..
Ashby [1927]	Jute leaves	16—28	..	6—8	..
	Bean stem	17—30	23·6	6—9	..
	Sesamum stem	18—29	..	7—9	..
Uppal *et al.* [1937]	Sorghum seedlings	10—24	..	6—10	..
Authors	Jute leaves	15·6—27·3	21·3	5·8—9·7	8·1
	Jute stems	15·6—27·3	19·9	7·0—9·8	7·9
	Cowpea leaves	15·6—24·2	19·0	6·8—7·8	7·7

Inoculation experiments

Shaw [1912] succeeded in infecting both the wounded and unwounded stems. Briton-Jones [1928] records successful infection on wounded stems, but it is not clear whether he obtained infection on unwounded stems also. It is found that infection readily occurs on mature stem when the surface of the stem is scratched and inoculated. Unwounded stems can also be successfully infected by maintaining humidity in the region where the inoculum is placed. In such cases the lesions remain localized. Where unwounded collar region of 15 days old plants is inoculated under high humidity, the discolouration is noticeable after 24 hours. The above ground parts of such plants are first to succumb and later the infection penetrates the roots. The cultures from live diseased plants and those from previous season's dead stubbles are equally virulent.

Briton-Jones [1928] could induce root infection of jute seedlings in inoculated gravel cultures under humid conditions. He was not able, however, to infect adult jute plants by soil inoculation. West [1931] grew jute plants to maturity in inoculated sand cultures, but the disease did not appear. As the disease is transmitted through the seed, it became necessary to sow individual seeds in sterilized soil in pots and to transplant only healthy young plants to inoculated soil. Forty plants 20 days old, when transplanted to inoculated soil, showed symptoms within 15—20 days, and succumbed to the disease, the percentage of mortality being 60. Roots of 20 days old healthy plants washed and dipped in a suspension of the culture when transplanted, produced symptoms after two days and subsequently died, the mortality being 85 per cent in a population of 40 . Twenty controls in each of the two experiments remained healthy. The soil, sterilized at 30 lb. pressure for one hour, was inoculated with 10 days old culture grown in Richard's medium. When five adult plants 75—90 days old were transplanted after washing their roots free of soil and dipping them in a suspension of the culture, the infection did not occur. All these inoculation experiments were carried out on plants grown in pots but the regulation of soil temperature or soil moisture in them was not possible. The failure of the fungus to infect adult plants may be due either to resistance offered by older roots or to the absence of proper conditions for favourable infection.

With the aid of an atomizer the pycnospores were sprayed over the leaves of one month old plants and these were kept under bell-jars for 36 hours. After a fortnight, lesions were observed on the different portions of the lamina followed by pycnidia. Pycnospores from these leaves yielded the sclerotial fungus. The original fungus was also recovered from the inoculation experiments.

No infection could be induced by spraying sclerotial suspension on leaves.

Development of disease in the field

Little was known as to the exact nature of the development of this disease in the field. The observations made in the previous two cropping seasons brought out some new aspects. With a view to gain more knowledge about these, the variety D 154 (*C. capsularis*) was grown in a field where heavy stem-rot was observed in the preceding years. Soon after germination, 150 plants

were marked out. For each plant under observation an index card was maintained and records of the weekly progress of the disease were kept till the maturity of the crop. From a study of these cards it is possible to trace the course of the disease from stage to stage. Weekly figures showing the number of plants in which a particular symptom was first observed are presented in Table II.

TABLE II

Frequency of plants showing a particular symptom for the first time

(Date of sowing—30 April 41 ; flowering commenced in 17th week ; harvest stage for fibre in the 21st week ; harvest of the seed crop 25th week onwards)

Weeks	Symptoms							
	Lesion on seedling	Lesion on leaf	Stem-rot	Stem shredd-ing	Stem canker	Girdl-ing of stem by lesion	Deaths	Lesion on capsule
1 . .	3	..	..	..	..	..	..	..
2 . .	21	..	..	..	..	..	..	..
3 . .	4	13	4	1	..	..	8*	..
4 . .	..	27	26	1	..	7	2*	..
5 . .	..	16	24	2	..	6	12	..
6 . .	..	27	15	11	..	7	11	..
7 . .	..	10	16	8	1	2	2	..
8 . .	..	7	4	11	1	..	1	..
9 . .	..	..	2	5	4	1	2	..
10 . .	..	1	2	2	3	..	1	..
11 . .	..	..	1	1	..	..	..	..
12 . .	..	..	2	3	3	1	1	..
13 . .	..	..	1	1	3	1	..	..
14 . .	..	..	1	..	2	1	1	..
15 . .	..	..	1	1	..	..	2	..
16 . .	..	1	2	..	1	..	2	..
17 . .	..	..	1	..	..	2	..	..
18 . .	..	..	..	..	..	1	3	..
19 . .	..	1	5	1	..	5	1	..
20 . .	..	..	..	2	1	4	6	..
21 . .	..	..	1	2	1	2	3	..
22 . .	..	2	5	..	1	4	3	..
23 . .	..	4	6	1	..	6	5	..
24 . .	..	..	..	2	..	4	7	3
25 . .	..	1	1	..	..	6	9	11
Total .	28	110	120	55	21	60	82	14
Percentage	18·6	73·3	80·0	36·6	14·0	40·0	54·6	9·3

* Damping off

The figures presented are from one year's data only and it is not the intention to use them for showing the extent of the disease which is known to vary from year to year. The primary aim is to confirm the previous two seasons' observations on the sequence of symptoms and the nature of epidemic. The conclusions on these two aspects are, therefore, based on three years' observations.

Out of the 150 plants kept under observation only 10 plants did not record any symptoms ; the remaining 140 plants showed one or more symptoms of stem-rot at some stage or other of their growth. The leaf and stem infections occurred a fortnight after the expression of seedling symptoms. The leaf infection generally leads to the infection of the stem at the nodes (Plate V, fig. 5).

In all, there were 82 deaths made up as follows :—

(*a*) Death attributable to *M. Phaseoli*—	
(*i*) due to damping-off	10
(*ii*) due to ringing	58
(*iii*) after stem-rot	10
Sudden deaths where M. *Phaseoli* was the probable cause—	
(*i*) after leaf infection	1
(*ii*) without any symptom	1
(*b*) Death due to other causes—	
(*i*) Whiteant attack after seedling and leaf infection . .	1
(*ii*) *Sclerotium rolfsii* after stem-rot	1
Total .	82

It is seen that the majority of deaths are largely due to the rot encircling the stem. The interval between the appearance of the stem-rot and the death of the plant ranges between one and twenty weeks. Where the top of the plant is attacked the death is quicker. Over 55 per cent of mortality occurred within two weeks of the commencement of the stem-rot. Attacked plants survive commonly by means of callus formation.

Regarding the extent of infection in relation to the stage of the crop, it is clear from Table III that more than 40 per cent of the plants caught the infection within the first month of their growth. By the eighth week after sowing, the cumulative infection had reached 84 per cent and the mortality which commenced in the third week had also reached a high level. The most critical period for the crop appears to be the first eight weeks of its growth for it is during this period that the disease is serious.

TABLE III

Percentage of infection and mortality

(Date of sowing—30 April 1941 ; flowering commenced in 17th week ; harvest stage for fibre in the 21st week ; harvest of the seed crop 25th week onwards)

Weeks	Symptoms				
	Healthy plants	Fresh infections on the healthy survivals	Cumulative infection	Deaths on the survivals	Cumulative deaths
1 . . .	98·0	2·0	2·0	..	..
2 . . .	84·0	14·3	16·0	..	..
3 . . .	73·4	12·7	26·6	5·3	5·3
4 . . .	53·4	27·2	46·6	1·4	6·6
5 . . .	43·4	20·0	56·6	8·5	14·6
6 . . .	27·4	35·9	72·6	8·6	22·0
7 . . .	21·4	21·9	78·6	1·7	23·3
8 . . .	16·0	25·0	84·0	0·9	24·0
9 . . .	15·4	4·2	84·6	1·6	25·3
10 . . .	14·7	4·3	85·3	0·9	26·0
11 . . .	14·7	..	85·3	..	26·0
12 . . .	14·7	..	85·3	0·9	26·6
13 . . .	14·7	..	85·3	..	26·6
14 . . .	14·7	..	85·3	0·9	27·3
15 . . .	14·7	..	85·3	1·8	28·6
16 . . .	14·0	4·5	86·0	1·8	30·0
17 . . .	14·0	..	86·0	..	30·0
18 . . .	14·0	..	86·0	2·8	32·0
19 . . .	13·4	4·8	86·6	0·9	32·6
20 . . .	13·4	..	86·6	5·9	36·6
21 . . .	13·4	..	86·6	3·1	38·6
22 . . .	11·4	15·0	88·6	3·2	40·6
23 . . .	8·0	29·4	92·0	5·6	44·0
24 . . .	7·4	8·3	92·6	8·3	48·6
25 . . .	6·8	9·1	93·2	11·7	54·6

It will be noted (Table III) that when the seed crop was ready for harvest, only 6·8 per cent of the plants remained completely free from the disease while 54·6 per cent had died. As the fibre crop is harvested a month earlier the corresponding figures for that stage are of interest. At that stage the percentages of healthy, infected and dead plants were 13·4, 48·0 and 38·6 respectively. Thus, after the fibre harvest stage the percentage of infection as well as mortality rise again. The most favourable period for the disease is when the plant is below two months or over four and a half months old. From the foregoing it appears that the destructiveness of the disease towards the harvest stage can be got over by earlier harvest as far as the fibre crop is concerned. The seed crop will, however, suffer considerably at the late stage.

Primary infection

The fungus is known to survive in soil and cause seedling infection and root-rot on a number of hosts. In jute fields the fungus perpetuates on stubbles in its sclerotial form. Where rotations are practised, other crops like linseed, sesamum or cowpea may form the alternate host. It is also found to survive on *Cyperus distans*—a common weed in Bengal.

Field observations indicate that excepting under high temperatures, the primary root infection is sporadic.

The fungus harbours on the seed, under the seed coat and within the cotyledons. In some samples as much as 30 per cent of the seeds were found to be infected. Most of the seedling symptoms described occur when contaminated seeds are sown under laboratory conditions. The relative importance of the seed-borne infection as against the soil-borne infection has not as yet been properly assessed. The work of Andrus [1938] with the bean disease caused by the fungus has shown that ' consistently more seedling infection is obtained when the seed is infected before planting than when infection is depended upon to occur from inoculum in the soil '. In view of this and also in view of the importance of the cotyledons in primary infection it seems that the contaminated seed is a more important source of primary infection.

Secondary infection

Pycnidia appear on the cotyledonary leaves and the hypocotyl within a fortnight after sowing or a week after the expression of the primary symptoms. Leaf lesions are noticed immediately in the vicinity of the originally infected plants. The evidence on hand indicates that the pycnospores released from diseased and infected seedlings cause this secondary infection. Abundant leaf infection has been noticed in the fields during and after heavy rains. Under prolonged, warm and humid conditions the leaf infection leads to severe outbreaks of stem-rot. From Table II it will be seen that only 18·6 per cent of plants got primary infection whereas at the seed harvest stage 93·2 per cent of plants were diseased. Thus 74·6 per cent of the total infection was apparently secondary.

When the weather during the first seven weeks of the crop is comparatively dry, the incidence of the disease at Dacca is less. Jute sown on low and *char* lands has been seen to suffer less than that grown on medium or high lands. The crop is sown very early (February—March) in *char* and low land areas and during the first two months of its growth the weather is mostly dry and the

conditions therefore are not as favourable for the spread of the disease as is the case with high land crops which are sown rather late in April or early in May.

Summary

The effect of stem-rot on the quality and outturn of fibre and the symptoms as they appear on various parts of the plant have been described.

The cultures of the fungus isolated from different parts of the diseased plants agree with Haigh's C strain of *Rhizoctonia bataticola* ; and the pycnospore measurements agree with those recorded by Ashby for *Macrophomina Phaseoli*.

The fungus is very virulent during the pycnidial stage and forms an important source of secondary infection. Pycnospores readily infect the leaves and the leaf infection spreads to the node through the petiole. The rot of the stem leads to either shredding, canker or wilting.

The primary root-rot usually occurs sporadically, late in the season, and also appears early in the season when high temperatures prevail.

The critical period for the crop and the most favourable period for the disease is before eight weeks or after four and a half months. Late infection is responsible for the contamination of seed.

It is suggested that infected seed is a more important source of primary infection than infection through the soil. The extent of stem-rot epidemic can be gauged from the primary infection, as, usually the secondary infection is four times the primary infection.

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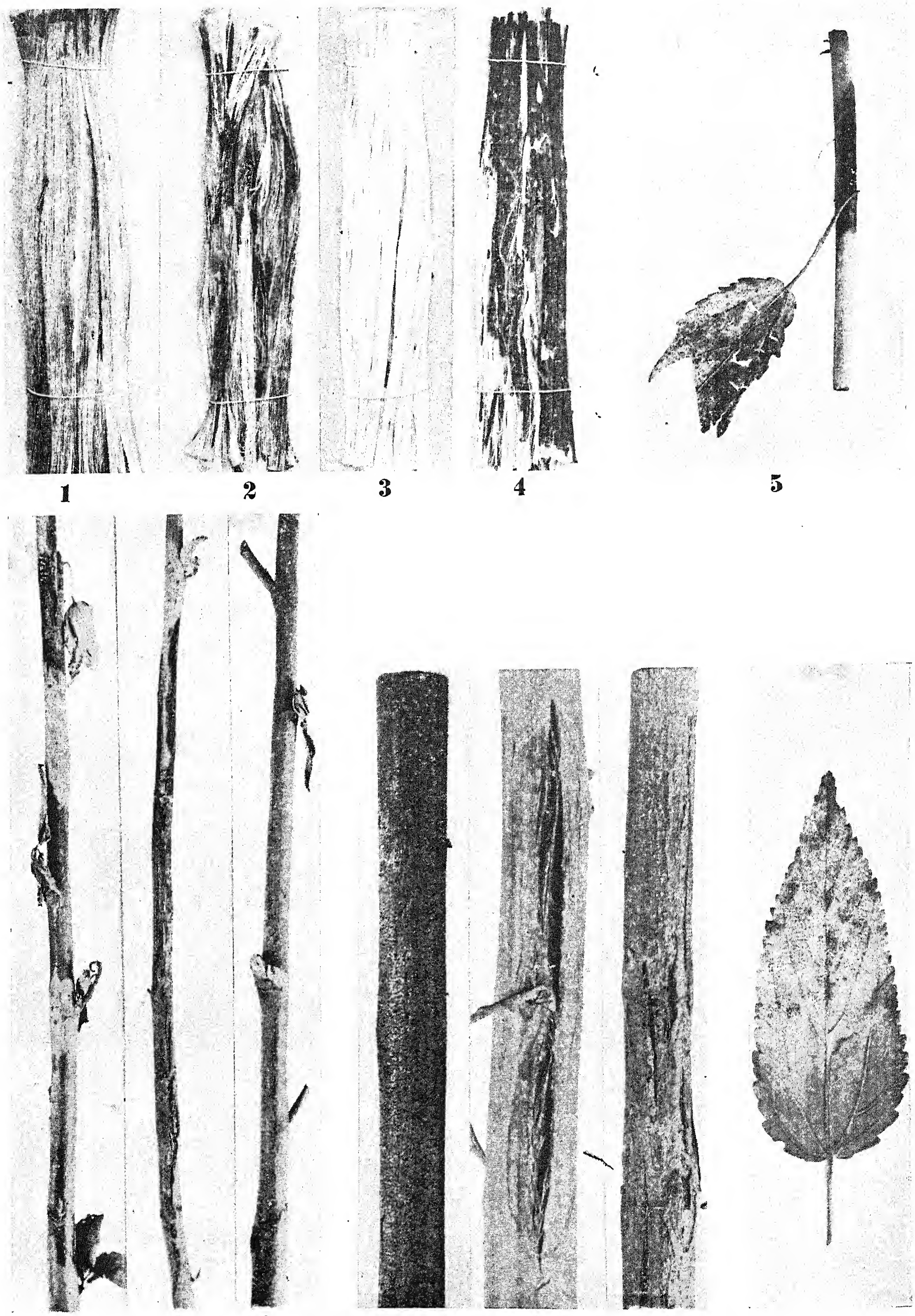


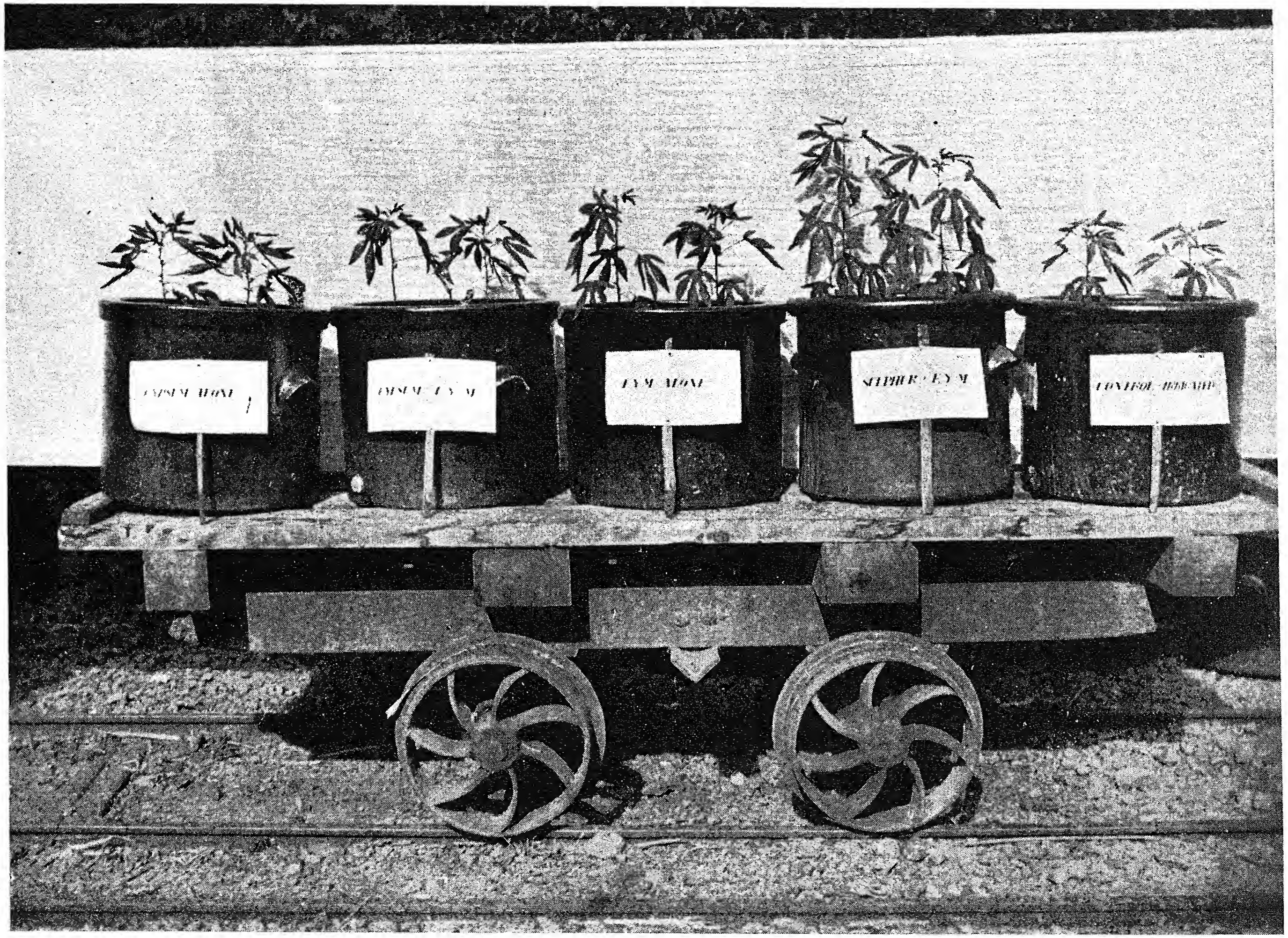
1 2 3 4 5

6 7 8 9 10 11 12

Stem-rot disease of jute due to *Macrophomina Phaseoli*

POT CULTURE EXPERIMENTS WITH RECLAIMED ALKALI SOILS WITH BANILLA COTTON

Sugarcane Research Scheme for Deccan, Padegaon



Treatment	Gypsum alone	Gypsum + F. Y. M.	F. Y. M. alone	Sulphur + F. Y. M.	Control irrigated
Yield of seed cotton in gm.	Nil	Nil	1·072	6·240	Nil
	Partially reclaimed	Partially reclaimed	Partially reclaimed	Reclaimed	Not reclaimed

SOILS OF THE DECCAN CANALS

IV. THE ALKALI SOILS, THEIR NATURE AND MANAGEMENT

BY

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(With Plate VI)

Introduction

Due to extensive occurrence of alkali soils in India and their proverbial infertility a study of these soils presents a very important problem both to the soil scientists and the agriculturists, and a co-ordinated attack on the subject is of vital importance in order to bring back millions of acres of such unproductive lands under proper cultivation. Seriousness of the situation has been only brought into prominence in most cases after the introduction of irrigation water to the arid regions as in the cases of the United Provinces, the Punjab, Sind and Bombay-Deccan. The so-called alkali soils of the United Provinces known as *usar* or *reh* were first investigated by the 'Reh Commission' in 1876, which was appointed to discover the cause of deterioration of lands which had been previously fertile. Leather [1897] in two exhaustive publications has dealt with all the salient points of evidence tendered before the Committee by Medlicott of the Geological Survey of India and others, adding the results of his own investigations on the *usar* lands not only of the United Provinces but also of the Punjab, Gujarat and the Bombay-Deccan. He has included all these saline and alkaline soils under the general term '*usar*'. All the evidence at that time pointed out that the general aridity of the land was the chief cause of formation of these soils. The scanty rainfall is not enough to wash out completely the salts naturally formed in the soil by weathering action. Both Leather (in the same publications) and Wadia [1936] have stressed the fact that under the north-Indian conditions an appreciable addition to the natural salts in the soils may be made by rivers, *nallas* and canals carrying salts in solution. Besides direct addition by surface washings, the raising of subsoil water is a serious consequence of irrigation. A fourth likely cause of formation of these soils, viz. the possible existence of a salt bed below the soil has been disproved by examination of actual bores taken at several places described by Leather.

Henderson [1920] has suggested some practical methods of salt land reclamation for north-west India. He was of opinion that washing of the salts

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into the subsoil was a very effective method of reclaiming such soils. After washing, the physical condition of the soil was improved by suitable cropping.

In the Punjab, Nasir [1923] in his researches on the barren soils of the Lower Bari Doab Colony has shown that though the alkali soils do not much differ in their mechanical analysis from the surrounding normal soil, the compaction, the shrinkage and the deflocculation of soil particles are due to the presence of harmful alkali salts. The lands are consequently rendered infertile and deficient in bacterial activity due to these alkali salts. The most suitable method to reclaim such soils, in his opinion, was to open artificial drains and to use gypsum with subsequent flooding to remove salts. Dalip Singh and Nijhawan [1932] have studied the physico-chemical changes accompanying the process of reclamation in alkali soils of the Punjab. They have presented data on the mechanical and chemical analysis of some of these soils and have ascribed the *kallar* trouble mainly to a deficiency in the exchangeable calcium. They have reclaimed these *kallar* soils by the application of gypsum and calcium chloride followed by farmyard manure. Recently, McKenzie Taylor and Mehta [1941] have stated that the soil deterioration in the Punjab is chiefly due to the presence of salts in the soil crust and to the formation of a zone of accumulation of salts with the introduction of irrigation. In studying the effects of salt distribution due to irrigation and growth of cotton and rice, they found that while cotton caused a re-distribution of salts originally present in the soil crust and a formation of zone of accumulation of salts, rice showed a complete leaching out of salts from the profile. From these observations they concluded that deterioration of lands in the Punjab containing salts can be prevented by growing rice.

The *usar* soils of the United Provinces have been successfully reclaimed near Cawnpore and Allahabad by the application of molasses. Dhar [1936] has stressed the fact that molasses, which contain about 60 to 70 per cent of carbohydrates and are distinctly acidic in reaction, can readily reclaim the alkali soils.

Tamhane [1920] has investigated the conditions of salt formation and accumulation in Sind soils. There, the appearance of *kallar* has been traced as not due to waterlogging, but to the downward and upward movement of irrigation water, which leaves the dissolved salts behind as the water evaporates. Such being the case, where there is no layer of sand as a safety layer, leaving the land fallow and absolutely out of cultivation favours the formation of *kallar*.

In the Bombay-Deccan, Mann and Tamhane [1910] in their investigations on the salt lands of the Nira valley have shown that the development of the salt lands in the Nira Canal area was due to the existence of the canal. The drainage condition of the soil being inferior, the subsoil water rose up to the surface causing the land to be waterlogged and salt-affected. They found that the lands can be prevented from being waterlogged and salt-affected by deepening the *nallas* and opening of feeder drains. Inglis [1927], and Inglis and Gokhale [1928] have described reclamation of salt-affected and waterlogged areas in the Deccan. Several land drainage schemes have been carried out in such areas and they have proved effective in most cases in improving the damaged lands by lowering the subsoil water level. Talati [1941] has

recently discussed the formation of waterlogged and salt-affected lands in the Deccan and has attributed causes of damage to the excessive amount of irrigation water applied by the cultivators and to the presence of salts in the soil. He has classified these damaged lands according to the presence of different amounts of salts in the soils and their *p*H values.

Although considerable work has been done in various places in India on the reclamation of the alkali soils, the knowledge regarding their nature is still very imperfect. This is mainly due to the lack of available data on the morphology of these soils and want of a clear understanding of the pedogenic processes leading to their formation. Hence it is difficult to forecast the probable behaviour of these soils under different intensities of irrigation and cropping. In the present paper, an attempt has been made to arrive at a rational system of management of these soils based on a thorough study of their morphology and chemistry, coupled with field experimentation to follow the dynamics of soil changes under different systems of irrigation, manuring, cropping and fallowing. Reclamation of badly alkaline soils by means of artificial methods has also been dealt with.

Experimental technique

Most of the field and laboratory methods given in a previous publication [Basu and Sirur, 1938] have been followed in connection with the investigations described in this paper. Only the additional methods employed are briefly indicated below :

Water extract of the soil. Soil shaken with water (soil : water ratio 1 : 5) for one hour in an end-over-end shaker and filtered through Pasteur Chamberland filter using Houston's pump.

(*a*) Sodium carbonate—Aliquot titrated with standard $KHSO_4$ solution using phenolphthalein as indicator [Harris, 1920].

(*b*) Calcium—By volumetric method of titration with potassium permanganate [Steenkamp, 1934].

(*c*) Sodium—Colorimetrically using zinc uranyl acetate method [Steenkamp, 1934].

Soil reaction. By the Biilman's quinhydrone method using a soil : water ratio of 1 : 2·5 [Wright, 1934]. Beckman's glass electrode *p*H meter has recently been employed to check these results. Agreements were very good up to a *p*H value of 9·0.

Dispersion coefficient. The percentage of clay in the soil was determined by the dispersion in pure water (A) and also by International method (B) and the dispersion coefficient worked out as A/B × 100.

II. Nature of alkali soils

On the Deccan canals a considerable area is covered by a peculiar type of soil which is characterized by impermeability, extreme hardness and occasional presence of undesirable salts on the surface, all of which affect adversely the plant growth. Locally known as '*chopan*', these soils are so far regarded as unsuitable for perennial irrigation and cane-growing. They occur generally in patches from a few acres to a few square miles in extent amidst well-drained

fertile soils of the tract. A large number of alkali soil profiles have been examined on the six major canals of the Deccan and some of the notable features of these soils are indicated below :

Soil depth and subsoil water-table. These soils are usually deep, the depth of the soil over *murum* (or decomposed rock) being sometime over 20 ft. but in certain exceptional cases soils having depths of 3 ft. to 4 ft. have also been found to possess similar characteristics. The subsoil water-table is generally struck between 7 and 12 ft. below the surface. Under waterlogged conditions, however, water-table reaches very near the surface, specially during the monsoon.

Soluble salts and p*H*. A zone of accumulation of soluble salts is a common characteristic of all these soils, the accumulation usually taking place in lower soil layers, i.e. in depths from 30 in. to 60 in. depending on the drainage condition of the soil profile. Exceptions are, however, found where the salts are found to accumulate even in surface layer where the soil occurs in a depression with or without an impervious subsoil. This may also happen where the subsoil water-table is near the surface and the water heavily charged with salts. The ratio of sodium/calcium in the accumulation zone has been found to vary from 0·62 to 9·25, and when the accumulation zone occurs in lower horizons ratios higher than 2 usually indicate a certain degree of compaction of the soil horizon. The *p*H value is usually high throughout the profile but the presence of soluble salts lowers the values to a certain extent depending on the sodium saturation of the complex and the nature of soluble salts.

Exchangeable bases. One of the characteristic property of these alkali soils is the high degree of saturation of the surface soil with sodium base, calcium being proportionately low. The sodium saturation varies from 10 to 40 per cent and calcium saturation from 55 to 85 per cent. This high saturation of the surface soil by sodium base is invariably reflected in the hard and compact nature of the soil. Wide variations in the exchangeable potash and magnesium are noted in different soils, but on the whole they are much higher than those present in the normal fertile soils. To what extent these latter bases affect the soil structure is not definitely known and further researches in these directions are in progress. In the present paper, only the proportion of exchangeable Ca and Na will be considered for assessing the extent of deterioration of these soils.

Soil structure. Usually these soils possess two or more horizons fairly well demarcated. The structure of the 'A' horizon varies from small clods to large clods, or laminated to nutty but is invariably hard and compact. Presence of large percentage of salts, however, modifies the structure of this horizon considerably, and dust-like or single-grained structure may also be seen where the percentage of free salts is too high. The 'B' horizon can be both 'loose and friable' as well as 'hard and compact' and the structure variation is great, viz. from single-grained to crumb or shaly to laminated or plate-like structure can be discerned. Hard and compact layer is usually accompanied by high degree of clay dispersion in water whereas loose and friable layer is associated by low dispersion. The alkalinity test (by phenolphthalein) shows that all these soils do not show presence of sodium carbonate and that there is a great deal of fluctuation of this constituent in the soil profile from season to season. Presence of gypsum crystals in the lower soil layers indicates

openness of soil structure, and these soils are usually well drained when brought under perennial irrigation.

Some typical profiles. Some typical alkali soil profiles are described below together with their physico-chemical properties, topography, etc.

(1) *Soil on flat topography with subsoil water-table below 10-15 ft. from the surface : 'B' horizon compact and impervious*

Profile description

Horizons	Depth	
A	0-24 in. . .	Greyish black soil—hard clods breaking into nut-like structure with a tendency for lamination in lower parts ; loam
B_1	24-32 in. . .	Definitely laminated structure—white nodules (small) of lime appearing ; compact
B_2	32-56 in. . .	Soil same as above but with numerous big white concretions of lime ; the structure less pronounced with increasing depth but very compact
C	56-68 in. . .	Practically yellowish white materia which effervesces strongly with dil. HCl (Same material continues to a great depth)

In a previous publication [Basu and Sirur, 1938], it has been stated that all mature deep soils in the Deccan show a zone of accumulation of salts in the profile. The reason for this is the great aridity due to which the products of soil weathering cannot leach out by normal rainfall (which amounts to 18 in. to 25 in.) unless the depth of the soil overlying *murum* or decomposed rock is limited to 2-3 ft. or less. Here the products of soil weathering accumulate gradually with time in the lower layers but in passing down the profile the soluble salts of the leachate get richer and richer in sodium than in calcium, as the bivalent ion calcium having more replacing power than the monovalent sodium ion, enters more in the complex in the upper layers, replacing more of sodium so that actually in the accumulation zone, Na/Ca ratio is usually high. When this high ratio is attained replacement of calcium by sodium starts (this usually takes place when the ratio is greater than 2·0 [Kelley, 1940] which soon brings about the sodiumization of the lower soil layers. This increased

TABLE I

Profile characteristics of alkali soil

Profile No. 1

Horizon 1	Depth in inches 2	Total soluble salts per cent 3	Sodium carbonate per cent 4	*p*H in water 5	Calcium carbonate per cent 6	Clay per cent 7	Dispersion coefficient per cent 8	Exchangeable: Calcium m. e. per cent 9	Exchangeable: Sodium m. e. per cent 10	Exchangeable: Calcium: sodium ratio 11
A . . .	0-12	0·69	0·011	8·91	5·26	50·50	33·67	35·75	5·86	6·10
	12-24	1·14	0·011	8·83	6·13	56·00	36·61	26·00	16·13	1·61
B_1 . . .	24-32	1·48	0·011	8·69	9·05	53·25	36·15	22·50	16·13	1·39
B_2 . . .	32-44	1·48	0·016	8·69	8·18	49·25	36·04	20·50	16·13	1·27
	44-56	1·31	0·021	8·64	6·72	47·50	44·74	14·00	18·75	0·75
C . . .	56-68	1·04	0·021	8·84	8·47	32·75	46·56	11·00	14·93	0·74

Water-soluble sodium/calcium ratio in accumulation zone = 8·03

sodiumization increases the impermeability of the 'B' horizon and the accumulation zone widens and moves upwards thus affecting the surface soil in time. The process is a slow one but is hastened when the profile shows definite eluviation of clay. These soils are characterized by a very hard and impermeable 'B' horizon which is well reflected in the low Ca/Na ratio of the exchange complex, high dispersion figures, presence of sodium carbonate and high *p*H values generally.

(2) *Soil profile occurring in a low-lying situation: Alkalization on the surface soil in spite of a fairly porous substratum: Subsoil water-table below 10 ft.*

Profile description

Horizons	Depth	
A	0-24 in.	Uniform greyish black soil; hard clods breaking with difficulty; black concretions of lime present; clay loam
B_1	24-58 in.	Mottled brown horizon, brown colour increasing with depth; crumb structure
B_2	58-84 in.	Uniform reddish brown material possessing a shaly structure—fairly porous. Presence of crystals of gypsum and white nodules of lime; proportion of lime nodules increasing with depth; silty loam (Very similar material extends up to 12 ft.)

Such a profile normally gets washings from the surrounding catchment area but as the slopes are gentle the soil solution which accumulates on the surface during the rains percolates easily downwards leaving the top soil almost free from high percentage of soluble salts. But as these soil-washings are normally richer in sodium (and also magnesium) through base exchange at higher slopes the 'A' horizon of this soil gets richer in these bases replacing exchangeable calcium in the form of chlorides, nitrates and sulphates, etc. which leach downwards and accumulate in the 'B' horizon where the proportion of Na/Ca is, therefore, usually low. Gypsum crystals also appear as concretions in this horizon. These soil leachings, therefore, act like a reclaiming agent for the lower soil layers and a porous 'B' horizon ultimately develops in time. The exchange Ca/Na ratio of the lower horizons is higher than that observed in the case of profile No. 1. The dispersion figures are also very low indicating definitely a more porous nature of this horizon.

(3) *Soil of medium depth occurring in a depression: 'B' horizon compact and impervious: Salt incrustations visible in patches on the surface*

Profile description

Horizons	Depth	
A	0-19 in.	Black soil—very compact from the beginning with pronounced lamination in the first eight inches; black nodules of lime present; clay loam
B	19-40 in.	Boundary not sharply demarcated but white concretions of lime appear in this horizon; more sticky and compact than above, which increases with depth
	Below 40 in.	*Murum* thoroughly disintegrated almost like sand—with profuse deposits of lime

TABLE II

Profile characteristics of alkali soil

Profile No. 2

Horizon	Depth in inches	Total soluble salts per cent	Sodium carbonate per cent	pH in water	Calcium carbonate per cent	Clay per cent	Dispersion coefficient per cent	Exchangeable		
								Calcium m. e. per cent	Sodium m. e. per cent	Calcium: sodium ratio
1	2	3	4	5	6	7	8	9	10	11
A	0-12	0·31	...	8·76	8·02	59·50	38·23	31·50	5·66	5·57
	12-24	0·93	...	8·66	8·85	60·75	37·04	24·50	11·52	2·13
B_1	24-36	1·90	0·011	8·54	10·37	59·25	3·38	31·50	11·85	2·66
	36-48	1·90	0·011	8·59	10·64	60·00	3·33	27·50	10·08	2·73
	48-58	1·90	0·016	8·58	11·75	64·75	...	26·50	11·52	2·30
B_2	58-72	2·80	0·005	8·33	7·33	64·00	8·59	37·00	8·86	4·18
	72-84	2·40	0·021	8·61	8·57	62·00	...	25·00	8·76	2·85

Water-soluble sodium/calcium ratio in accumulation zone = 0·96

In this particular case there is an accumulation zone in the surface layer which must have been derived from the washings received from the catchment area, the soil solution being richer in sodium than in calcium salts. As the sodiumization has extended up to the 'B' horizon the permeability of this horizon is not good. This will be also evident from the high dispersion figures as also from the high pH values. The beneficial salts of calcium which are usually formed as a result of base exchange in the upper soil horizon must have been partially leached out into the *murum* below (due to shallow depth of overlying soil layer) thus depriving the 'B' horizon of the advantages which accrue otherwise in such cases when the depth of the soil is considerable as in the previous case. Such types of soil may also develop when the lower soil layers are sandy or when the water-table is near, thus helping the removal of calcium salts which are formed as a result of base-exchange reactions in the upper soil layers.

TABLE III

Profile characteristics of alkali soil

Profile No. 3

Horizon	Depth in inches	Total soluble salts per cent	Sodium carbonate per cent	pH in water	Calcium carbonate per cent	Clay per cent	Dispersion coefficient per cent	Exchangeable		
								Calcium m. e. per cent	Sodium m. e. per cent	Calcium: sodium ratio
1	2	3	4	5	6	7	8	9	10	11
A	0-8	2·28	...	8·43	10·95	55·75	40·81	30·00	8·71	3·44
	8-19	0·83	...	8·74	11·82	43·00	66·86	22·00	7·20	3·06
B . . .	19-31	0·42	...	8·97	15·19	57·75	52·38	18·50	8·06	2·29
	31-40	0·42	...	8·84	16·36	57·00	46·49	18·00	7·46	2·41

Water-soluble sodium/calcium ratio in accumulation zone = 6·07

(4) *Soil with surface salt crust formed as a result of nearness of saline subsoil water-table*

Profile description

Horizons	Depth	
A_0	0-2 in.	Surface crust; breaks up into dry sand-like material with greyish black colour; whitish efflorescе of salt present; sandy loam
A_1	2-8 in.	Darker colour than above; slightly laminated to structureless; moist
	8-18 in.	Same as above but loose and friable with a tendency for lamination. Roots of trees visible
B_1	18-27 in.	Definitely compact and laminated with large number of black nodules present. Only a few roots visible here
B_2	27-36 in.	Sandy and gritty material with presence of white and black lime nodules
B_3	36-48 in.	Compacted sandy material full of lime nodules—whitish concretions mixed with soil (Water-table struck at 4 ft.)
C	48-54 in.	Black material (soil) absent; white limy material forming hard cement-like structure containing innumerable black nodules and sandy patches

All these soils are characterized by a surface crust of salts which are richer in sodium than calcium. Saline subsoil water works from below affecting the lower soil horizons more at first, and then travelling upwards when the soil solution gets gradually lower in Na/Ca ratio due to base-exchange reactions. Exchangeable calcium falls very low in such soils specially in lower layers due to continuous reactions of the following types :

$$\mathrm{Ca}\,x + 2\mathrm{NaCl} \rightarrow \mathrm{Na_2}x + \mathrm{CaCl_2} \qquad (1)$$

$$\mathrm{Ca}\,x + \mathrm{Na_2CO_3} \rightarrow \mathrm{Na_2}\,x + \mathrm{CaCO_3} \qquad (2)$$

of which, probably the reaction represented in (2) is more effective. The compaction of the lower horizons is indicated by high dispersion figures as well as low Ca/Na ratios in the exchange complex.

A broad classification of alkali soils on the basis of the compaction of the 'B' horizon

Generally speaking, it may be said that all deep soils which show a zone of accumulation of salts, and also soils of medium depth which contain a salt profile due to topographic conditions are potentially alkaline soils. All these soils possess well-defined structures (probably with the exception of actually waterlogged soils) and can be classed under the world group 'alkali soils with structure' of Glinka [1927] although the morphological features of these soils are somewhat different from those of the Russian 'Solonetz'. According to Sigmond's [1938] system of soil classification, these soils definitely come under the soil order 'sodium soils' as sodium base mainly determines their characteristic structure and field behaviour. The presence of free salts is only a temporary phase in these soils, and a classification based on the nature of these

TABLE IV

Profile characteristics of alkali soil

Profile No. 4

Horizon	Depth in inches	Total soluble salts per cent	Sodium carbonate per cent	pH in water	Calcium carbonate per cent	Clay per cent	Dispersion coefficient per cent	Exchangeable		
								Calcium m. e. per cent	Sodium m. e. per cent	Calcium sodium ratio
1	2	3	4	5	6	7	8	9	10	11
A_0 . .	0-2	3·64	...	8·09	7·15	31·50	11·90	35·00	16·12	2·17
A_1 . . .	2-8	3·20	0·016	8·51	7·98	42·75	72·53	11·50	8·76	1·31
	8-18	2·24	0·021	8·64	8·66	50·75	100·00	12·50	10·33	2·21
B_1 . . .	18-27	1·18	0·032	8·37	10·73	51·50	100·00	5·50	9·83	0·56
B_2 . . .	27-36	0·32	0·053	8·52	12·10	29·25	100·00	24·00	15·50	1·55
B_3 . . .	36-48	0·42	0·058	8·56	10·32	41·50	95·18	1·50	17·92	0·08
C . . .	48-54	0·35	0·064	8·62	13·07	21·00	100·00	5·50	10·89	0·51

Water-soluble sodium/calcium ratio in accumulation zone = 3·89

salts without any reference to the structure profile will be of very little practical value. Various pedogenic processes which lead to the alkalization of these soils have been partially discussed in this paper (and will be fully discussed elsewhere), from which it will be seen that all these processes can be broadly classified into two groups for the purposes of assessing their suitability for perennial irrigation: (1) Processes responsible for the formation of a compact 'A' horizon but which at the same time help in the development of a porous and well-drained 'B' horizon; (2) Processes which develop ultimately the compaction of both 'A' and 'B' horizons, thus bringing into existence the worst types of alkali soils. These latter soils resemble more closely the 'Solonetz' group of soils and will be referred to in this paper as belonging to 'C' family while the former soils having more affinity to 'Steppe' alkali soils will be called as 'B' family, the names 'B' and 'C' being retained as the first of these members were named in an earlier paper [Basu and Sirur, 1938].

The causes which lead to the formation of these alkali soils can be stated as under: (1) Great aridity of the tract when combined with great soil depth, (2) topographic situation which affects the surface soil due to salt washings from the surrounding catchment area, and (3) nearness of saline subsoil water brought about usually by indiscriminate irrigation. In the formation of alkali soils due to (1) it is not always necessary to have an impermeable subsoil as found essential in the case of Hungarian alkali soils by Sigmond [1927]. Secondly it is not essential to have great soil depths for the formation of alkali soils as it was supposed formerly because the causes (2) and (3) can bring about alkalization even in the case of medium depths of soils.

So far as the reclamation of these sodium soils is concerned they are placed in a very much more advantageous position when compared with the European alkali soils of this group because of the presence of a large reserve of calcium carbonate in the entire profile. For the amelioration of these soils the prerequisite condition to help the reaction of calcium carbonate with the sodium

clay is to create a humid condition, i.e. opposite of what actually has taken place during the formation of these soils. In other words it is necessary to produce an artificial leaching condition to remove the soluble product of reaction out of the soil zone as represented by the following simple equation :

$$CaCO_3 + Na_2 \times \rightleftharpoons Ca \times + Na_2CO_3$$

in order that these soils may be permanently improved. Irrigation, therefore, seems to be the fundamental need for the amelioration of these soils. Of course, it is pre-supposed that the drainage condition of the subsoil will be fairly good in order that the reaction represented in the above equation can proceed in the right-hand direction. Such a case is presented in all soils belonging to the group 'B' where the 'B' horizon is permeable. A series of experiments to study the effects of irrigation, manuring, cropping and fallowing on this group of soil are described in section III while reclamation by artificial methods is discussed in section IV. In the case of 'C' group of soils, great precautions will have to be taken if such soils are to be brought under irrigation. The provision of a drainage system will be an essential feature in these soils, at least in the earlier stages of crop growing. Often times, these latter soils are found to be completely unfit for the growing of irrigated crops when artificial methods recommended in section IV will be found useful.

III. Management of alkali soils

It has already been emphasized that one of the most undesirable properties of these soils from the point of view of their management lies in their possession of an invariably hard and compact surface soil. Due to this property considerable difficulties are encountered by the cultivators in securing a proper tilth, and consequently the germination of seeds and root developments are hindered in earlier stages. Further, due to an impervious nature of these soils a badly puddled condition is usually created on irrigation, and proper nitrification is checked. For these reasons the crops suffer badly whenever proper precautions are not taken in cultivating and irrigating these soils. As the bad nature of these soils is mainly due to high saturation of the clay complex by sodium base, their improvement can only be achieved through the replacement of sodium by calcium following the well-known methods of base exchange. As there is always an abundant supply of calcium carbonate in all these alkali soils the above reaction can take place only through irrigation.

Comprehensive experiments were, therefore, laid out on a typical alkali soil where the 'B' horizon is definitely well-drained. Such an alkali soil was obtainable at the Padegaon Farm, and its description is given in profile No. 2 in the previous section. As besides irrigation, both manuring and cropping are supposed to help favourably the base-exchange reactions by the production of carbon dioxide as a result of improved bacterial activities and root reactions, the following series of experiments were designed in single plots to assess the soil changes after a number of years :

(A) Irrigation and manuring

(B) Cane cropping and fallowing

(C) Rotational cropping

The determinations of only exchangeable calcium, sodium and soil reaction are done to study the nature of soil colloids as affected by different factors of cane growing. Any improvement in soil colloids due to the effects of these factors will be judged by the increase in the calcium/sodium ratio, and in lowering of the soil reaction.

A. *Irrigation and manuring series*

This experiment was started in single plots (size 18·15 ft. × 12 ft. or 1/200 of an acre) in a block with proper bunds, and arrangement for measuring the water by means of a standing wave flume. The treatments on acre basis were as follows :

Water	(1) 70 A″ (2) 95 A″ (3) 120 A″
Manure	(*i*) Nitrogenous—300 lb. N—(4) & (5)
	(4) Sulphate of ammonia
	(5) Farmyard manure
	(6) Green-manure (sunn)
	(*ii*) Phosphatic—600 lb. P_2O_5
	(7) Superphosphate
	(*iii*) Potassic—600 lb. K_2O
	(8) Muriate of potash
	(9) Sulphate of potash
Control	(10) Dry plot

All the treatments from No. (4) to (9) received irrigation of 95 A″ per annum excepting the treatment (6). The changes in the exchangeable calcium, sodium, calcium : sodium ratio and soil reaction will be seen from Table V where the original values and the values after four years of experimentation are recorded. The critical differences for significance have been worked out from previous experience.

It will be observed that in all cases the exchangeable calcium has increased and in some cases the changes are considerable. Even in dry control plot there has been significant increase in exchange calcium, and this may be attributed to the effect of bunding which brings about the leaching down of rain water within the profile in a more efficient way than when there is no bund. Increasing doses of water have effected progressive increases in exchangeable calcium. Addition of manure has helped further the base-exchange reaction only in the cases of sulphate of ammonia, farmyard manure, and superphosphate. The last treatment, however, has not reached the level of significance over the control dose of 95 A″ of water. Reduction in sodium base has taken place in most cases ; but only in the manured plots the changes are appreciable, the greatest reduction being observed in the farmyard manure-treated plot. It will be seen that the reductions in sodium base in all cases are far lower than the corresponding increases in calcium, thus showing that the replacement of other bases by calcium must have also taken place simultaneously. From the changes in the calcium : sodium ratios it will be evident that great improvements in the soil colloids have taken place in most of the manured treatments. Even in the case of irrigation alone, 95 and 120 acre-inches treatments have significantly improved the soils. The first four treatments in order of efficacy are farmyard manure > sulphate of potash > muriate of potash > sulphate of ammonia. As regards soil reaction, both the water treatments 95 A″ and

TABLE V

Effect of irrigation and manuring on the exchangeable calcium, sodium, calcium/sodium ratios and soil reaction

Treatment	Exchangeable calcium m. e. per cent			Exchangeable sodium m. e. per cent			Calcium/sodium ratio			pH in water		
	Original	After 4 years	Difference	Original	After 4 years	Difference	Original	After 4 years	Difference	Original	After 4 years	Difference
Water 70A″	41·00	45·50	4·50	4·58	4·53	—0·05	8·95	10·04	1·09	8·72	8·64	—0·08
Water 95A″	39·50	47·75	8·25	4·53	4·43	—0·10	8·72	10·78	2·06	8·89	8·60	—0·29
Water 120A″	39·50	49·25	9·75	4·63	4·53	—0·10	8·53	10·87	2·34	8·86	8·62	—0·24
Sulphate of ammonia	39·00	49·00	10·00	4·68	3·66	—1·02	8·34	13·38	5·04	8·80	8·36	—0·45
Farmyard manure	40·00	50·00	10·00	6·10	2·93	—3·17	6·56	17·07	10·31	8·81	8·72	—0·09
Green manure	39·75	44·75	5·00	5·23	3·84	—1·39	7·60	11·66	4·06	8·79	8·74	—0·05
Superphosphate	36·75	46·75	9·00	5·16	4·03	—1·13	7·13	11·35	4·22	8·89	8·72	—0·17
Muriate of potash	38·00	43·75	5·75	5·84	3·58	—2·26	6·51	12·22	5·71	8·80	8·50	—0·30
Sulphate of potash	38·25	46·75	8·50	6·33	3·50	—2·83	6·04	13·36	7·32	8·84	8·80	—0·04
Control dry	39·00	41·00	2·00	6·33	6·20	—0·13	6·16	6·62	0·46	8·89	8·86	—0·03
Critical difference for significance	..	..	1·58	..	..	0·99	..	..	1·50	..	..	..

120 A″ have appreciably lowered the pH values when compared with the dry control while amongst the manure treatments only sulphate of ammonia has given higher drop in pH than the 95 acre-inches of water. Thus, although there has been greater improvement in soils due to manuring, this effect is not reflected in their pH values. The basic nature of these fertilizers partly accounts for this fact while in the case of farmyard manure increase in buffering capacity may be held responsible for such peculiar action.

B. *Cane cropping and fallowing series*

In this experiment 12 plots of dimensions 45·5 ft. × 24 ft., i.e. 1/40 of an acre, were laid out with different systems of cane growing and fallowing as shown below, the crops being continuously grown year after year :

(1) Manjri standard method (cane grown according to standard Manjri system, i.e. 150 lb. N given half as sulphate of ammonia and half as cake)

(2) Continuous plant cane (unmanured)

(3) Continuous plant cane (manured ; basal dose of 40,000 lb. per acre farmyard manure ; top-dressing 150 lb. N per acre as sulphate of ammonia and cake in equal proportions)

(4) Continuous ratoon (unmanured)

(5) Continuous ratoon (manured ; for the first crop same manure as in plant cane and for succeeding ratoon crops, top-dressing with 100 lb. N in equal proportions of sulphate of ammonia and cake)

(6) *Adsali* (unmanured)

(7) *Adsali* (manured ; basal dose of 40,000 lb. farmyard manure per acre, top-dressing 200 lb. N of which 75 lb. N applied as sulphate of ammonia and the rest as cake. The crop allowed to grow for 22 months, allowing only two months for the preparation of land for next cropping)

(8) *Adsali* (Cultivator's method, crop harvested after 18 months and land left fallow till next planting ; manure same as in manured *adsali* crop)

The different systems of fallows were :

(9) Uncultivated and irrigated (Uc. I.)

(10) Uncultivated and un-irrigated (Uc. Ui.)

(11) Cultivated and irrigated (C. I.)

(12) Cultivated and un-irrigated (C. Ui.)

For the sake of abbreviation these fallows will be referred to in the subsequent paragraphs by the letters indicated in brackets. Irrigated fallows were introduced in the above system primarily to leach out the salts and secondly to encourage the natural weed growth in this alkaline soil.

Excepting in the case of Uc. Ui. fallow there have been increases in exchange calcium after four years of experimentation in all cases, although in the case of manured cane, *adsali*—cultivator's method, and C. I. fallow the increases are not appreciable (Table VI). It is curious to note that increases in exchange calcium are more in all the unmanured canes than in manured ones. Among the fallows, Uc. I. fallow shows the highest increase while Uc. Ui. shows actually a lowering (which is, however, not significant). In the case of exchange sodium all cane treatments excepting unmanured plant cane and cultivator's *adsali*, have shown significant reduction. Among the fallows, beneficial effects of irrigation in lowering exchangeable sodium is evident, weeds actually

TABLE VI

Effect of cane growing and fallowing on the exchangeable calcium, sodium, calcium/sodium ratios and soil reaction

Treatment	Exchangeable calcium m. e. per cent			Exchangeable sodium m. e. per cent			Calcium/sodium ratio			pH in water		
	Original	After 4 years	Difference	Original	After 4 years	Difference	Original	After 4 years	Difference	Original	After 4 years	Difference
Cane												
Manjri standard method	38·75	41·15	2·40	9·01	6·08	−2·93	4·30	6·77	2·47	8·34	8·21	−0·13
Unmanured . .	36·25	42·00	5·75	5·42	3·84	−1·58	6·69	10·94	4·25	8·34	8·22	−0·12
Manured . . .	39·50	41·25	1·75	6·15	3·53	−2·62	6·42	11·70	5·28	8·79	8·31	−0·48
Ratoon												
Unmanured . .	36·15	39·15	3·00	9·38	6·91	−2·47	3·86	5·67	1·81	8·66	8·44	−0·22
Manured . . .	39·00	41·55	2·55	7·30	5·04	−2·26	5·34	8·25	2·91	8·46	8·32	−0·14
Adsali												
Unmanured . .	36·85	40·90	4·05	8·32	5·27	−3·05	4·43	7·77	3·34	8·61	8·34	−0·27
Manured . . .	34·85	38·25	3·40	11·07	6·23	−4·84	3·15	6·14	2·99	8·74	8·27	−0·47
Cultivator's method .	35·80	36·00	0·20	10·34	8·60	−1·74	3·46	4·19	0·73	8·42	8·19	−0·23
Fallow												
Cultivated and irrigated	37·85	39·05	1·20	8·86	6·16	−2·70	4·27	6·34	2·07	8·46	8·21	−0·25
Uncultivated and irrigated	38·40	41·60	3·20	9·88	6·09	−3·79	3·89	6·83	2·94	8·32	8·21	−0·11
Uncultivated and unirrigated	39·50	38·25	−1·25	10·93	11·60	0·67	3·61	3·30	−0·31	8·29	8·52	0·23
Cultivated and unirrigated	39·55	41·75	2·20	8·00	7·76	−0·24	4·94	5·38	0·44	8·37	8·32	−0·05
Critical difference for significance	..	..	2·02	..	..	2·18	..	..	1·38	..	..	..

helping the process still further. Finally, it will be seen that significant increases in the calcium/sodium ratios, thus indicating the improvement in the soils, have taken place in case of all the cane treatments excepting in the *adsali* according to cultivator's method, the descending order of improvement of the first four treatments being manured plant cane $>$ unmanured plant cane $>$ unmanured *adsali* $>$ manured *adsali*. This inefficiency of the cultivator's *adsali* treatment in improving the soil colloid seems to be mainly due to the longer period of summer fallow as practised by the cultivators, which is detrimental in these soils. This aspect is fully discussed later on. In the case of fallows, both the irrigated fallows show significant improvement. Among the cane treatments only manured plot has shown appreciable lowering in *p*H value. The lowering in *p*H in cultivated and irrigated fallow is of the same order as that of irrigated control (i.e. 95 A″) while cultivated and unirrigated fallow is similar to dry control. In spite of greater improvement in soil condition in the uncultivated and irrigated plot the lowering in *p*H is less pronounced. Uncultivated and unirrigated fallow indicates the danger of fallowing these soils in the natural condition.

C. *Rotational crop series*

Several common rotational crops usually grown in this tract were taken in small plots (size 43·35 ft. × 20 ft., i.e. 1/50 of an acre) in a block for two years in succession and soil samples analysed. The result after two years of experiment is given in Table VII. The following crops were grown: (1) *Rabi jowar* (*Andropogon sorghum*), (2) Wheat, (3) Berseem (*Trifolium alexandrinum*), (4) *Shevri* (*Sesbania aegyptiaca*), (5) Cotton, (6) Tobacco, (7) *Dhaincha* (*Sesbania aculeata*) and (8) Rice.

The 'difference' column shows that the exchangeable calcium has increased in all cases excepting in wheat (where there is a slight reduction). Rice, *shevri*, berseem and tobacco have shown significant increases. There have been definite lowerings in exchangeable sodium in all treatments, berseem and *dhaincha* showing the highest figures. From the increases in the calcium/sodium ratios it can be judged that even within two years of crop growing considerable improvement in the soil complex has taken place in all cases, the order of superiority for the first four crops being berseem $>$ rice $>$ *dhaincha* $>$ cotton. It is interesting to note that the four crops mentioned above showed significant improvement even after first year of cropping. In this rotational series the changes in *p*H values are very little excepting in the case of cotton, although the improvement in the soil (as indicated by increase in base ratios) is greatest in the case of berseem.

In order to see whether the loss of exchangeable sodium in the soils due to cropping can be accounted for, by the removal of this base by crops, analysis of these rotational crops was undertaken. This revealed the fact that while the actual uptake by plants varied from 6 to 43 lb. in case of different crops the loss of exchangeable sodium amounted from 422 lb. to 1488 lb. per acre-foot of soil. Thus the plant uptake can account only for an insignificant part of the sodium lost from the soil due to cropping. Root reaction (i.e. production of carbon dioxide by roots), therefore, appears to play an important role in the reclamation of these alkali soils under irrigation, whereby the replaced sodium

TABLE VII

Effect of rotational crops on the exchangeable calcium, sodium, calcium/sodium ratios and soil reaction

Crop	Exchangeable calcium m. e. per cent			Exchangeable sodium m. e. per cent			Calcium/sodium ratio			pH in water		
	Original	After 2 years	Difference	Original	After 2 years	Difference	Original	After 2 years	Difference	Original	After 2 years	Difference
Rabi jowar	33·00	34·00	1·00	6·60	5·43	—1·17	5·00	6·26	1·26	9·03	8·98	—0·05
Wheat	32·50	31·00	—1·50	7·60	5·84	—1·76	4·28	5·31	1·03	8·87	8·80	—0·07
Berseem	31·25	33·50	2·25	6·84	4·03	—2·81	4·57	8·31	3·74	8·93	8·89	—0·04
Shevri	29·00	33·00	4·00	6·83	6·05	—0·78	4·25	5·46	1·21	9·01	8·98	—0·03
Cotton	32·25	34·00	1·75	7·07	5·43	—1·64	4·56	6·26	1·70	9·06	8·76	—0·30
Tobacco	31·00	33·00	2·00	6·95	5·76	—1·19	4·46	5·73	1·27	8·98	8·89	—0·09
Dhaincha	31·00	32·00	1·00	7·07	4·98	—2·09	4·38	6·43	2·05	8·81	8·74	—0·07
Rice	30·25	34·25	4·00	5·76	4·63	—1·13	5·25	7·40	2·15	8·84	8·77	—0·07
C. D. for significance	..	..	1·94	..	..	0·78	..	..	0·53	..	..	..

ion (as sodium carbonate) is completely leached out. In the case of sugarcane, however, it is found that a considerable amount of sodium is removed by different varieties, and the sodium base removed by the crop may amount to about one-third of the total loss from the soil as a result of cane growing.

Harmful effect of summer fallowing and methods of mitigating it. It has already been shown in a previous experiment that fallowing without irrigation is actually harmful to the soil as it tends to lower the calcium/sodium ratio of the complex. It was thought necessary, therefore, to study the movement of soluble calcium and sodium in the profile to find out the danger period when the alkalization of the surface soil can take place due to differential movements of these bases. Water-soluble calcium and sodium were determined monthly in 6 in. depths of a *chopan* soil profile during the whole year and the results are given in Table VIII. It will be observed that the soluble calcium up to a depth of 24 in. is fairly low (with very little fluctuation during the year) while below this depth the figures are invariably very much higher throughout the year. In the case of sodium also the lower layers (i.e. 24-30 in. and 30-36 in.) contain much more of the base than the upper 24-in. layers but the actual sodium in these upper layers is five to ten times more than calcium. There is a steady rise of sodium, specially in the surface 6 or 12 in. of soil from January to May, after which the sodium content goes on decreasing. A slight drop in May from April may be due to a heavy shower of rain (1·60 in.) which fell in the latter half of April. From June to November (i.e. during the monsoon) a steady low level is maintained. It appears, therefore, that the sodiumization of the surface soil due to the movement of water-soluble salts is likely to be most active during the summer months, i.e. from March to May. Thus summer fallowing in these soils would be a dangerous practice.

In order to study whether growing of lucerne and *shevri* (which can be conveniently grown during summer months) would be effective in checking the rise of sodium salts in the soil profile, soil samples were analysed for two periods during April and May and the results are given in Table IX. It will be clear that in the case of lucerne considerable lowering in soluble sodium takes place over the entire profile while with *shevri* the improvement is only in the first foot of soil during the first period but proves slightly better in the second. With regard to calcium there is a general increase of this constituent over the entire profile. The experiment thus stresses the importance of growing irrigated crops like lucerne and *shevri* on the land during the summer period.

IV. Reclamation by artificial methods

In the previous section it has been shown that considerable improvement in soil can be achieved by simple process of cropping where irrigation and manuring are practised. There are, however, certain extreme types of alkali soils existant on the tract (such as degraded 'C' type soil) where crop growing is often not possible. In such cases it was felt that previous reclamation of soils by artificial methods will be required. For this purpose a new set of experiments was started involving the use of farmyard manure, gypsum, sulphur and molasses. The results of this experiment are described in this section.

TABLE VIII

Movement of water-soluble calcium and sodium in the profile

Depth in inches	Bases	(mg. per 100 gm. of soil)											
		January	February	March	April	May	June	July	August	September	October	November	December
0-6	CaO	14·00	33·04	33·60	50·40	32·48	32·50	40·90	43·70	39·20	47·60	44·80	57·68
	Na_2O	121·36	143·67	189·39	316·46	255·10	154·32	150·60	162·33	145·34	158·22	148·80	97·64
6-12	CaO	12·88	12·32	13·44	11·20	14·56	19·60	15·10	14·56	14·00	12·88	15·10	20·16
	Na_2O	105·04	100·00	173·61	271·74	156·25	192·30	114·77	119·04	116·82	115·74	93·98	87·41
12-18	CaO	14·56	14·00	21·80	12·05	17·36	17·90	14·00	17·90	14·56	11·76	21·28	22·40
	Na_2O	134·40	116·82	162·33	242·71	126·26	168·61	113·63	130·20	145·36	117·92	100·00	120·19
18-24	CaO	16·86	21·28	11·76	10·90	29·12	57·70	15·70	14·00	17·90	11·76	26·88	26·88
	Na_2O	130·20	148·80	156·25	378·78	245·09	347·22	164·47	109·64	156·25	131·57	107·76	138·88
24-30	CaO	120·96	262·08	300·16	150·90	102·48	206·10	156·80	70·00	103·60	180·88	20·72	106·96
	Na_2O	290·72	312·50	390·60	595·23	265·95	490·19	531·91	352·11	337·83	347·22	189·38	245·09
30-36	CaO	206·08	243·60	303·52	245·00	221·20	259·30	226·80	169·68	202·72	190·40	162·40	264·32
	Na_2O	337·84	403·22	462·96	735·29	297·61	520·83	555·55	438·58	396·82	297·61	260·41	396·82

This experiment was conducted for two years in small plots (14 ft. × 8 ft. or 1/400 of an acre) with provision for flooding with suitable bunds. Shallow drains (about 2 ft. deep) were also maintained for the removal of excess water

TABLE IX

Movement of water-soluble calcium and sodium (mg. per 100 gm. of soil) in the profile under dry (control), lucerne and shevri

—	Depth in inches	April		May	
		Calcium oxide	Sodium oxide	Calcium oxide	Sodium oxide
Dry (control)	0-6	50·40	316·46	32·48	255·10
	6-12	11·20	271·74	14·56	156·25
	12-18	12·05	242·71	17·36	126·26
	18-24	10·90	378·78	29·12	245·09
	24-30	150·90	595·23	102·48	265·95
	30-36	245·00	735·29	221·20	297·61
Lucerne	0-6	17·90	100·80	28·56	162·33
	6-12	19·90	77·16	19·04	92·59
	12-18	8·40	97·65	96·88	164·47
	18-24	226·25	378·78	235·76	219·30
	24-30	246·70	462·96	156·80	160·26
	30-36	219·25	595·23	143·92	215·51
Shevri	0-6	30·80	166·66	24·06	73·52
	6-12	12·30	134·40	14·00	45·62
	12-18	13·15	328·94	15·70	81·17
	18-24	184·50	714·28	203·28	201·61
	24-30	224·00	694·44	316·96	208·33
	30-36	294·00	806·45	259·28	201·61

in-between the plots, the distance between the adjacent plots being 8 ft. A series of nine plots (consisting of 3 plots in 3 rows) was started in the first year, and the following treatments were tried :

(1) Sulphur + farmyard manure
(2) Control (irrigated)
(3) Sulphur alone
(4) Sulphur + farmyard manure + gypsum
(5) Gypsum + farmyard manure
(6) Sulphur + gypsum
(7) Farmyard manure alone
(8) Control (dry)
(9) Gypsum alone

The dose of sulphur was ½ ton per acre, gypsum 1 ton and farmyard manure 5000 lb. per acre. The reclaiming agents were applied to the soil in the month of June every year and were allowed to react during the monsoon. The treated plots were then flooded to the height of 6 in. every day for five days continuously and allowed to drain for the next five days during the closure of the canal. This process was repeated for a period of three months in succession. During this experiment the heights of standing water after 24 hours were recorded in each treatment. Considerable improvements, as judged by the drainage condition of the treated plots, were observed, specially in the cases of treatments No. (1) and (4) in the first year and also in (3) and (6) in the second year. The soil samples were collected at the end of every year and the analytical data after two years of experimentation are only given in Table X.

It will be evident that significant increase in exchange calcium has taken place in all cases except in the dry control where it has shown a slight lowering. The highest increase is recorded in the case of sulphur + farmyard manure + gypsum treatment. Reduction in exchangeable sodium is observed in all cases, the most prominent among them being the treatments (1), (4), (3) and (6), i.e. where sulphur is applied alone or in combination. From the point of view of final improvement, as judged by calcium/sodium ratio, it will be noted that significant increases have taken place in all cases excepting dry control. The first four treatments in descending order of improvement are as follows : Sulphur + farmyard manure > sulphur + gypsum + farmyard manure > sulphur alone > sulphur + gypsum.

In the case of molasses, experiment was started after one year in three adjacent plots and continued for two years as in the previous case. The treatments were :

(10) Molasses 10 tons per acre
(11) Molasses 5 tons per acre
(12) Control (irrigated)

In short it may be said that although molasses have brought about reclamation of these soils, they are definitely inferior when compared with the sulphur treatments, although superior to farmyard manure or gypsum alone.

Considerable lowering in *p*H values is observed in all the treated plots when compared with the controls. The drops in *p*H are round about 0·49 to 0·66 in most of the treatments excepting the 'sulphur + gypsum' treatment where

TABLE X

Effect of reclaiming agents on the exchangeable calcium, sodium, calcium/sodium ratios and soil reaction

Treatment	Exchangeable calcium m. e. per cent			Exchangeable sodium m. e. per cent			Calcium/sodium ratio			pH in water		
	Original	After 2 years	Difference	Original	After 2 years	Difference	Original	After 2 years	Difference	Original	After 2 years	Difference
Sulphur + Farmyard manure	33·50	37·75	4·25	8·96	2·30	—6·66	3·74	16·41	12·67	8·94	8·28	—0·66
Control irrigated	32·50	35·00	2·50	9·90	8·96	—0·94	3·29	3·91	0·62	8·73	8·72	—0·01
Sulphur alone	32·50	34·75	2·25	9·48	3·93	—5·55	3·43	8·84	5·41	9·03	8·54	—0·49
Sulphur + Gypsum + F. Y. M.	32·25	39·50	7·25	9·21	2·68	—6·53	3·50	14·74	11·24	8·99	8·37	—0·62
Gypsum + F. Y. M.	32·75	34·50	1·75	9·48	6·45	—3·03	3·46	5·35	1·89	9·03	8·46	—0·57
Sulphur + Gypsum	32·50	36·75	4·25	10·08	4·48	—5·60	3·22	8·20	4·98	9·39	8·49	—0·90
F. Y. M. alone	31·00	33·25	2·25	10·08	6·45	—3·60	3·08	5·16	2·08	9·03	8·46	—0·57
Control dry	33·00	30·75	—2·25	10·08	8·71	—1·37	3·27	3·53	0·26	9·03	8·86	—0·17
Gypsum alone	31·50	34·25	2·75	10·40	7·53	—2·87	3·03	4·55	1·52	9·11	8·46	—0·65
C. D. for significance	..	..	1·06	..	..	0·68	..	..	0·31	..	..	..
Molasses (10 tons)	30·50	34·50	4·00	10·08	5·30	—4·78	3·03	6·51	3·48	..	..	..
Molasses (5 tons)	28·75	39·00	10·25	9·95	7·47	—2·48	2·89	5·22	2·33	..	..	..
Control irrigated	30·50	34·50	4·00	10·40	9·82	—0·58	2·93	3·51	0·58	..	..	..

the lowering is 0·90. In the control plots the changes in soil reaction are practically very little. There appears to be, however, no clear-cut relation between the extent of reclamation as judged by the increase in the exchange calcium/sodium ratio, and the lowering in *p*H. Whatever the initial *p*H values may be, the process of reclamation seems to have brought down the final *p*H values after two years to round about 8·4—8·5 excepting in the best reclaimed soil, 'sulphur + farmyard manure', where the *p*H is lowered still further. It is curious to state here that these soils when leached in contact with calcium carbonate attain a *p*H value of nearly 8·2. Thus the lowest limit that can be expected for these soils to attain in any reclamation experiment is 8·2, and the actual lowering in *p*H is virtually governed by the state of original *p*H level in these alkaline soils. The success of a reclamation experiment can, therefore be judged roughly by the final *p*H when it approaches the limiting value of 8·2 in water. The KCl *p*H has shown lowering in values of the same order in all cases including even the control plots. These values are not reported here as they do not show any striking variations between the reclaimed and unreclaimed soils.

Fertility status of the reclaimed soils. In order to study the effect of reclamation on the fertility status of the soils, Neubauer's seedling method [Stewart, 1932] for available phosphate and potash was tried with six soils having calcium/sodium ratios varying from 16·41 in the best reclaimed soil (sulphur + farmyard manure), 5·16--4·55 in the partially reclaimed soils (farmyard manure alone and gypsum alone) to 3·55 in the unreclaimed control (dry). As regards available phosphate the reclaimed soils showed higher values (7·9 mg. per 100 gm. soil) as compared with the control (3·9 mg. per 100 gm. soil) thus indicating more availability of phosphate by reclamation. In case of available potash, however, the two best reclaimed soils showed very high figures (20·1 and 30·2 mg. per 100 gm. soil) but the farmyard manure-treated soil which was only partially reclaimed showed high availability (28·9 mg. per 100 gm. soil) in spite of fairly low value of calcium/sodium ratio (i.e. 5·16). This peculiar behaviour of the soil reclaimed by farmyard manure was noticed in the pot-culture experiment with cotton and also reflected in the quality of *gul* produced from cane grown on this soil, which is discussed later.

Since it is well known that carbon dioxide evolution is an index of microbiological activities in the soil, evolution of carbon dioxide was measured to study the improvement in the soils by reclamation. Respiration studies were carried out for a period of 12 days and the total production of carbon dioxide from different soils compared. The results indicated that the quantity of carbon dioxide evolved was in good agreement with the state of reclamation of the soil, the maximum evolution being given by the best reclaimed soil and the least by the controls (both dry and irrigated), partially reclaimed soils giving intermediate values. The total production in the 12-day period was in the following descending order :

Sulphur + farmyard manure $>$ gypsum $>$ farmyard manure $>$ dry control $>$ irrigated control

Pot-culture work with cotton using the reclaimed soils. The soils obtained from the reclamation experiment were subjected to a pot-culture experiment with cotton (Banilla variety) as a test crop to ascertain to what extent these improvements as judged by the base ratios hold good when the actual soil

fertility is measured in terms of crop yields. The crop was grown in the usual way in five replicates and the results are briefly discussed below :—With the exception of farmyard manure treatment (where the calcium/sodium ratio is 5·16) the opening of the bolls took place only up to calcium/sodium ratio of 8·20. Among the best reclaimed soils, sulphur + gypsum + farmyard manure treatment produced more yield of cotton per boll although sulphur + farmyard manure treatment gave the highest total yield. From the points of view of height and total dry matter also the two reclaimed soils top the list. Photo showing the growth of cotton plant in certain selected treatments is given in Plate VI (facing page 157).

Reclamation and the quality of gul. In the experimental plots, where the reclamation of soil by artificial method was tried for two seasons sugarcane (variety Co 360) was grown in order to finally find out how the quality of *gul* is influenced by the various methods of reclamation. It may be mentioned here that the quality of *gul* is one of the most important consideration with the cultivators, the *gul* obtained from these alkaline soils being usually of an inferior quality. *Gul* blocks were, therefore, carefully prepared, separately from sugarcanes grown in these plots and assessed by the local experts with the following results. *Gul* produced from the farmyard manure-treated plot was best from all points of view, and sulphur-treated plots also (alone and in combination) gave superior quality of *gul*. On the whole, soils with higher calcium/sodium ratio gave better colour and test of *gul* than the control soils, (both irrigated and dry) where the ratios were lower. Thus the beneficial effect of reclamation on the quality of *gul* is clearly manifested.

V. General conclusions and summary

A considerable part of the commandable area of the Deccan canals is occupied by a peculiar type of alkaline soil which is characterized by impermeability, extreme hardness and occasional presence of harmful salts, all of which affect adversely the plant growth. Locally known as *chopan* these soils are so far regarded as unsuitable for perennial irrigation and cane growing. It was, therefore, thought desirable to undertake detailed investigations on the nature of these soils in order to classify them from the point of view of irrigation suitability and devise means for their management. Results of these studies are briefly indicated below :

(1) From an examination of a number of alkali soil profiles situated on different canals it was found that the most common feature of these soils is the high saturation of the surface soil with sodium base which is responsible for the above-mentioned undesirable qualities of these soils.

(2) All these soils possess a zone of accumulation of salts in the profile, and depending on the nature and position of this zone in the profile, the alkalization and the consequent development of a structure profile take place. These genetic characteristics undoubtedly place these soils in the broad world group of 'alkali soils with structure' described by Glinka [1927].

(3) The causes of alkaline degradation of these black cotton soils have been traced to (*i*) great aridity of the tract combined with great soil depth, (*ii*) topographic situation which affects the surface soil due to salt washings from the surrounding catchment area, and (*iii*) nearness of saline subsoil water.

(4) The soil-forming processes leading to the alkalization of the profiles can be broadly divided into two groups for the purposes of assessing the suitability for perennial irrigation : (*a*) Processes responsible for the formation of a compact 'A' horizon but which at the same time help in the development of a porous and well-drained 'B' horizon ; (*b*) Processes which develop ultimately the compaction of both 'A' and 'B' horizons thus bringing into existence the worst types of alkali soils. These latter soils resemble more closely the 'Solonetz' soils while the former soils have more affinity with the 'Steppe' alkali soils.

(5) Since these alkali soils are formed as a result of extreme aridity in climate, creation of a humid condition by irrigation was thought essential for their reclamation. Experiments were, therefore, laid out on a typical alkali soil (with a porous 'B' horizon) on the farm to study the interaction of water, manure, cropping and fallowing on the soil colloids. Results indicate in a general way that all the above factors of cane-growing help in reducing sodium colloid and in increasing the proportion of calcium colloid, which are so essential for building up of desirable soil structures. Appreciable lowering in *p*H values was also observed in these cases.

(6) In the case of dry covered fallow it was noticed that a slight lowering in the Ca/Na ratio was followed by a rise in *p*H value. The harmful effect of dry fallowing was, therefore, apprehended which was further corroborated by detailed studies on the movement of soluble calcium and sodium salts in the profile. Summer fallowing was observed definitely harmful in this respect and the most effective means of checking it was found to be growing of irrigated crops like lucerne and *shevri* during this period.

(7) In the case of the worst type of alkaline soils (where the 'B' horizon is usually impervious) it may not be possible to grow any irrigated crop with success. In such cases it will be necessary to reclaim the soils by artificial methods. It was found that the best reclaiming agent for these soils is a mixture of sulphur and farmyard manure applied at the rate of half a ton and two tons per acre respectively. Molasses (10 tons per acre) was also found useful but it proved less effective when compared with the sulphur mixture. In alkaline soils showing impervious 'B' horizon provision for shallow drains appears to be essential when they are to be brought under perennial irrigation.

(8) When the soils at different stages of reclamation (as judged by Ca/Na ratios) were compared in a Neubauer's test for available potash and phosphoric acid it was noticed that the reclaimed soils were definitely superior in their available constituents when compared to partially reclaimed or unreclaimed soils. Similar superiority of the reclaimed soils was also observed in their microbiological activities as tested by the evolution of carbon dioxide from these soils.

(9) A pot-culture experiment with cotton indicated that a calcium/sodium ratio higher than 8·0 was essential for the proper growth and boll formation in cotton.

(10) The quality of *gul* was also found to be considerably improved when canes were grown in soils having a high Ca/Na ratio.

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A MOSAIC DISEASE OF BOTTLE GOURD

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(With Plates VII & VIII and two text-figures)

IN May and June, 1941, during observations on the occurrence of diseases of vegetable crops in zamindars' fields round about Delhi, a mosaic disease of bottle gourd (*Lagenaria vulgaris* Ser.) was seen to occur commonly. Large number of plants were affected and the infection appeared to be widespread. The symptoms were more marked on younger leaves and the leaf surface showed a combination of dark green to pale green areas.

A large number of isolations made from the diseased material did not give any fungal or bacterial growth. Microscopic examination of the diseased tissue also did not reveal the presence of any organism. The nature of the symptoms of the disease and failure to isolate any organism from the diseased tissue suggested a virus as the cause.

Experiments conducted with a view to study the symptomatology, transmission and properties of the casual virus are reported in this paper.

Material and method

The original inoculum of bottle gourd mosaic virus was taken from a mature, fruit bearing, infected bottle gourd plant. Young bottle gourd plants grown under insect-proof conditions were infected by mechanical inoculation. Later on, transfers were made to young plants periodically in order to provide a stock of freshly infected plants for inoculation work throughout the course of the investigation.

The standard extract for inoculation was prepared by crushing to a fine pulp in pestle and mortar a known weight of young infected leaves which had previously been washed and dried in folds of filter paper adding a small quantity of water from time to time. To every gram of leafy material 1 c.c. of water was added. This was then pressed through muslin by hand.

Inoculations were carried out by dusting the leaves with finely powdered carborundum and smearing the leaf with a piece of absorbent cotton wool dipped in fresh extract from the diseased plant. This method usually gave 100 per cent infection. Controls were similarly treated except that extract from healthy plants was used as inoculum. Every care was taken to maintain aseptic conditions and all the apparatus used was sterilized according to requirements of each experiment.

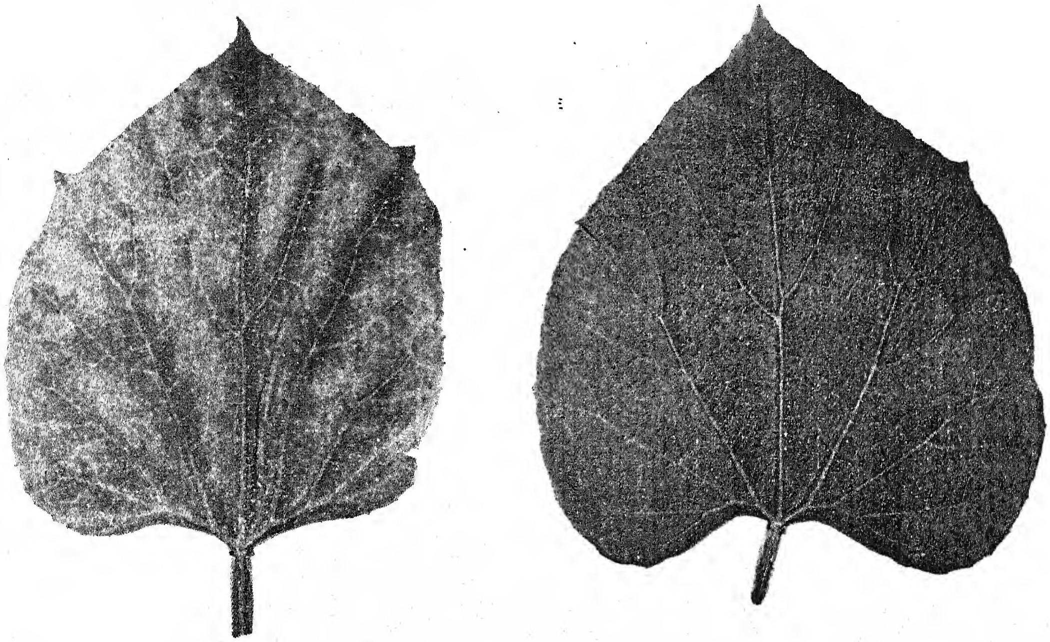

FIG. 1. Infected and healthy leaves of bottle gourd

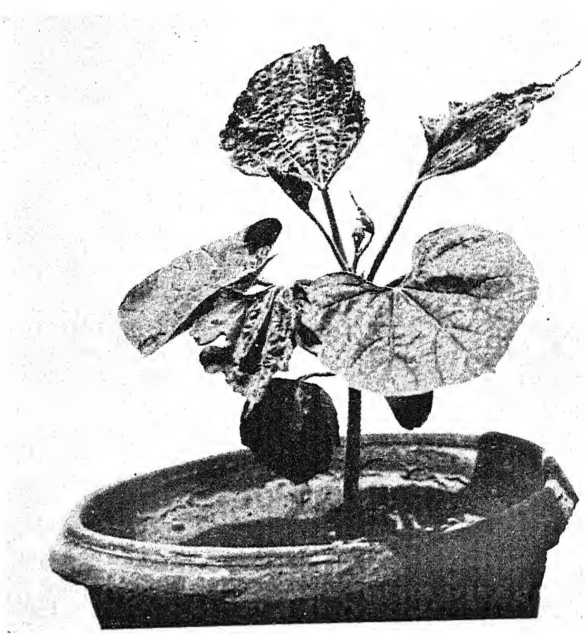

FIG. 2. Infected bottle gourd plant

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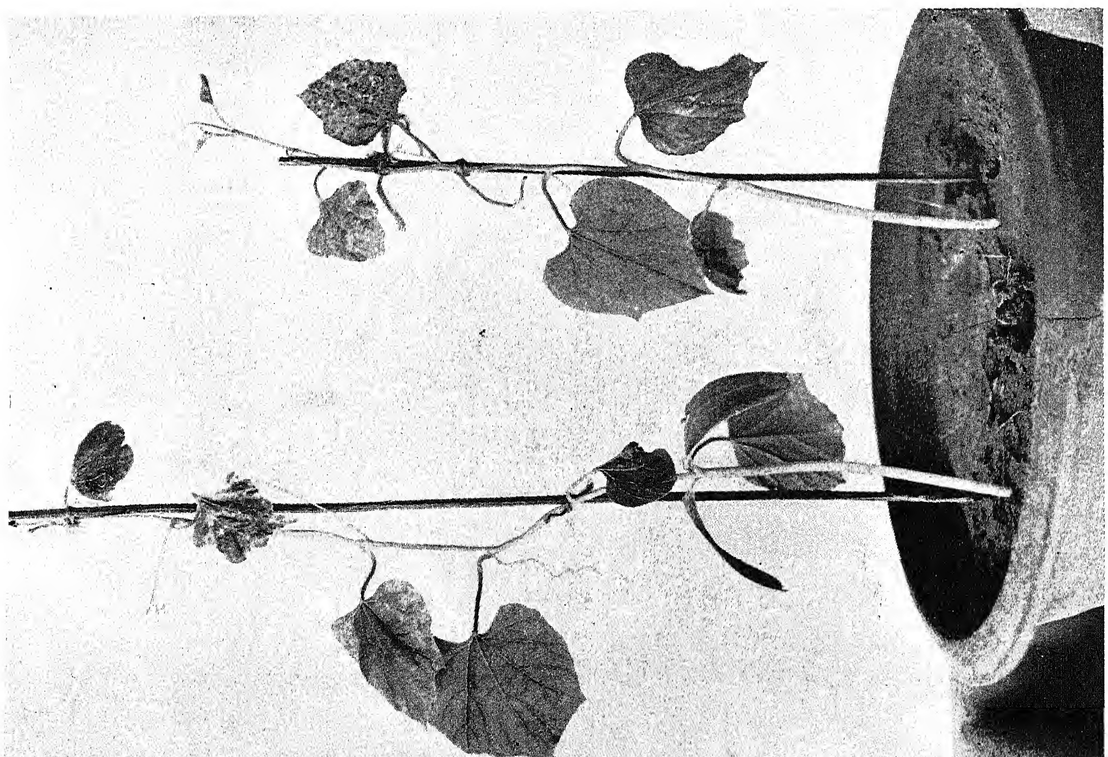

FIG. 1. Infected bottle gourd plants

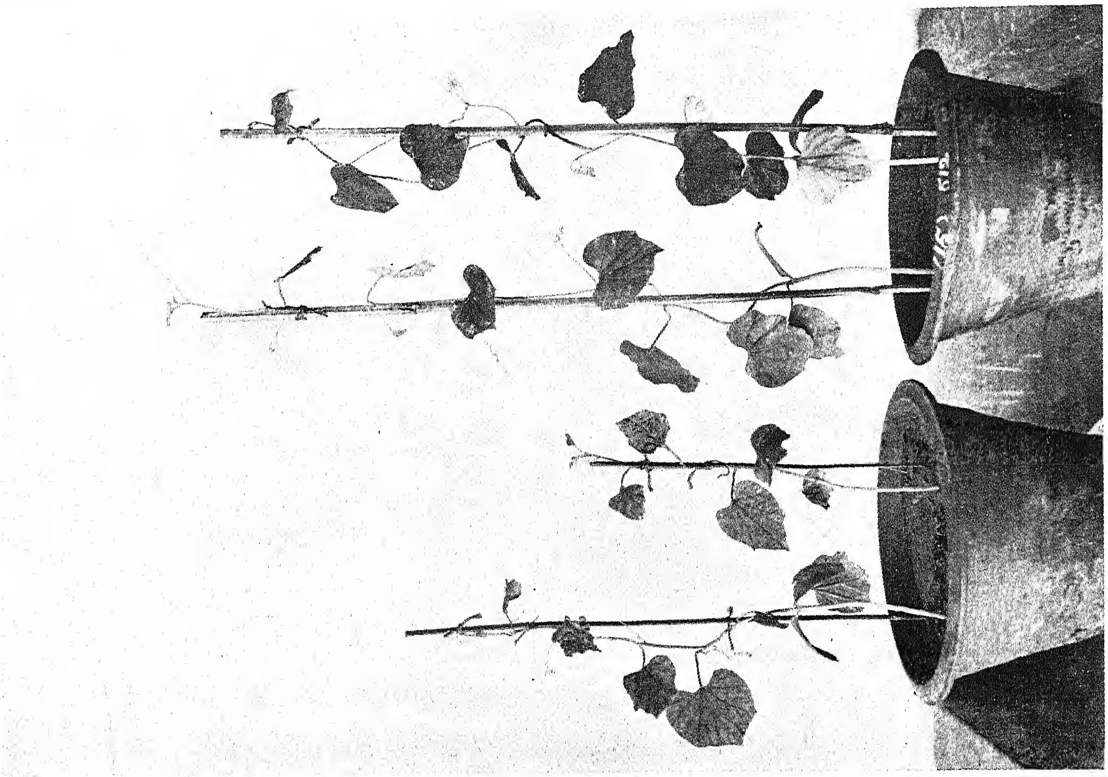

FIG. 2. Infected and healthy plants of bottle gourd of the same age (18 days) after inoculation

The plants raised in sterile soil under insect-proof conditions were as a rule inoculated when they had developed the first three to four true leaves and for any one experiment plants of the same age were employed so that the results could be strictly comparable. The test plants were always kept under observation for at least four weeks.

Symptoms of the disease

The symptoms of the disease produced on bottle gourd by mechanical inoculations in the insect-proof house were similar to those observed on plants growing in the cultivators' fields as well as our experimental plots exposed to normal infection. During the growing season, i.e. March to August, the first symptoms of infection in the insect-proof house appear six to eight days after inoculation but during winter months the infection may take 28 to 30 days or more. The growth of plants during these months is extremely slow. The best time for infection coincides with the optimum period for growth. The inoculated leaves seldom show signs of infection but the succeeding young leaves exhibit the first marked symptoms of the disease. Early symptoms are in the form of broad chlorotic streaks between the major veins along which a deep green portion persists. Later, however, the chlorotic portion gradually expands thus limiting the green portion to either side of the veins. Plate VII, fig. 1 shows a leaf of an infected and a healthy plant.

Young infected leaves may either be distorted with wavy and irregular outline or may have a wrinkled surface, or both. Occasionally, the mid-rib arches above the centre of the leaf surface with the result that the leaf apex as well as the margins are curled downwards. Characteristic dark green blisters occur commonly and are seen scattered over the entire pale green leaf surface. These appear as small convex areas on the upper surface of the leaf. They are the result of curving in of the lower surface of the leaf and are not due to the thickening of a portion of the leaf surface. These blisters are partly responsible for the wrinkled appearance of the leaves. Plate VII, fig. 2 and Plate VIII, fig. 1 show infected bottle gourd plants.

The infection is always systemic and all the succeeding leaves show symptoms of the disease in the form of chlorotic streaks, or quite often as irregular light green and dark green mottling in a limited portion or the whole surface of the leaf. Some leaves show complete chlorosis with dark green blisters, others exhibit regular mottling in the form of minute light green and dark green specks all over the leaf surface. In about seven weeks' time the older leaves dry up and are shed. The plants infected early in the season remain small in size, blossom sparingly and set fewer fruits which are usually normal.

Twelve healthy plants 20 days old and of the same size were selected. Six were infected with bottle gourd virus and six were kept as controls. The growth of the plants regarding their height, leaf area, size and number of internodes and size of petioles 16 days after infection and of the control plants are compared in Table I. The statistical significance of the differences in different parts of healthy and diseased plants recorded were evaluated by Bessel's method [Shaw, 1936]. In this method a ratio of the difference of the two means to the probable error of the difference is calculated from the data and according as this is a greater or smaller number, the greater or smaller is the probability that the results recorded are significant. When the ratio

M. D./P. E. D. is just above 3·2 the results are on the margin of significance. The ratio M. D./P. E. D. for all the comparisons shown in Table I lies between 6 and 12. This represents an enormously high probability that the height, number and area of leaves, number and size of internodes and size of petioles is significantly greater in healthy plants. Plate VIII, fig. 2 shows healthy and infected plants of the same age 18 days after inoculation.

TABLE I

Effect of infection on growth of different organs of plant

Plant No.	Height of plants (in.)		Leaf: Total number per plant		Leaf: Average area per leaf in square inches		Internodes: Total number per plant		Internodes: Mean size per plant (in.)		Petioles: Mean size per plant (in.)	
	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
1	16·5	11·0	8	6	4·31	2·89	5	4	2·14	1·42	1·45	1·01
2	30·0	12·0	11	6	6·86	2·51	8	3	3·18	1·90	1·35	1·08
3	26·0	9·4	8	6	5·41	1·43	6	3	3·26	1·07	1·67	0·77
4	20·0	10·5	8	6	4·10	2·94	5	2	2·86	0·98	1·15	0·94
5	15·5	14·5	9	7	3·27	3·02	5	5	2·32	1·98	1·46	1·12
6	38·5	11·5	12	6	6·80	3·31	9	4	3·81	1·30	1·36	1·05
P. E. D.	1·6188		0·5034		0·2743		0·3561		0·1268		0·0364	
M. D./P. E. D.	7·9		6·2		8·9		7·8		11·7		11·2	

Internal structure. Vertical sections of leaves both from healthy and diseased plants were cut and examined microscopically. Leaves from the plants of the same age and approximately from same position were taken.

Epidermis of the diseased leaves may remain unaffected but in leaves which show wrinkling and puckering the epidermal layer is not regular and well defined but shows some depressions and eruptions. Size and shape of palisade cells is markedly affected. They become more broad than long and are

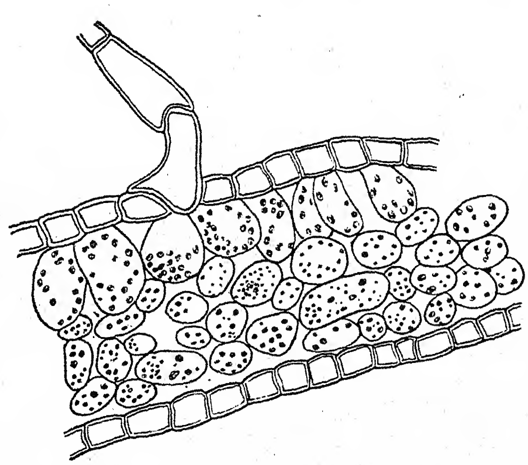

FIG. 1. Vertical section of infected bottle gourd leaf (×304)

more or less cuboid in shape and are loosely arranged as compared to those in healthy leaves where they are greater in length and are compactly arranged. The chloroplasts in the palisade cells of infected leaves are few in number. They either aggregate in the centre of the cell or in a corner or may be arranged along the walls of the cells so that the remaining portion of the cell appears almost empty and colourless. The chloroplasts are sometimes evenly distributed in the cell. In healthy leaves the cells are almost completely filled with the chloroplasts.

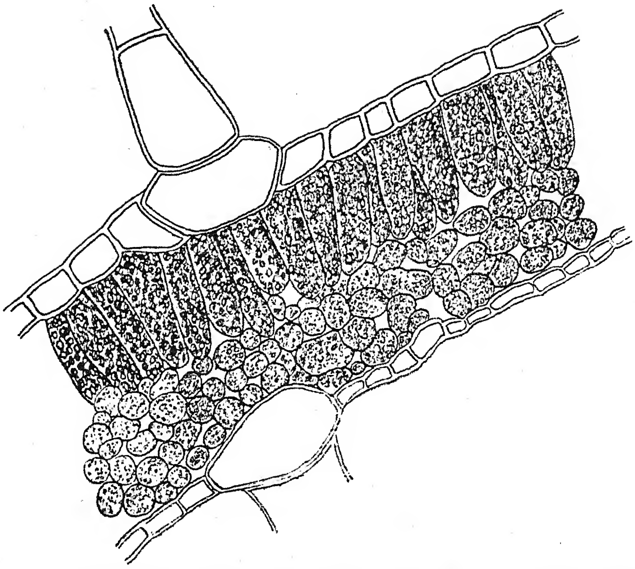

Fig. 2. Vertical section of healthy bottle gourd leaf ($\times 304$)

The spongy parenchyma in the diseased leaves is loosely arranged and the cells appear to be a little larger in size.

The chlorotic portion of a diseased leaf is slightly thinner than the deep green portion, including the green blisters of the same leaf or any part of a healthy leaf.

There is no appreciable difference in the internal structure of green blisters of diseased leaves and any portion of a green healthy leaf. Figs. 1 and 2 show vertical sections through an affected and a healthy leaf respectively.

Host range

With a view to determine the host range of the virus other cucurbits in addition to bottle gourd were tested. This included cucumber, bitter gourd, melon, water-melon and vegetable marrow. Inoculations were carried out by the method already described on young plants grown in the insect-proof house. The symptoms produced on these hosts are described below.

Cucumber (*Cucumis sativus* L.). Symptoms appear about 10 days after inoculation. The inoculated leaves do not show any symptoms of the disease. The first visible symptom is the clearing of veins and the subsequent leaves either show mild chlorosis of the whole leaf with green blisters, the number of which varies greatly, or crumpled and wrinkled condition with chlorosis or mottling limited to the margins or the veins. The growth of the infected plants is adversely affected.

Bitter gourd (*Momordica charantia* L.). The first symptoms are observed only on the youngest leaves about eight days after inoculation. There is no clearing of veins but the leaves show regular light green and dark green mottling over the whole leaf surface. In addition to the mottling, sometimes there is a darkening of the central portion which is usually limited to either side of the

mid-rib. The typical blisters formed on bottle gourd or cucumber are, however, absent.

Melon (*cucumis melon* L.). The symptoms are visible about eight days after inoculation. The first obvious symptom is the clearing of veins of the older leaves. Later the young leaves show light mottling which in some leaves is in the form of a regular pattern. The mottling may cover the whole portion of the leaf or may be restricted to a particular portion. The infected leaves may or may not be crumpled.

Water-melon (*Citrullus vulgaris* Schrad). The infection does not occur so readily and the first symptoms appear approximately after 17 days. The youngest leaves show light mottling which is in the form of light green and dark green spots almost uniformly distributed over the whole surface. There is no wrinkling and distortion of the leaves. The symptoms are not much pronounced.

Vegetable marrow (*Cucurbita pepo D. C.*). The symptoms are first visible on younger leaves only. These show clearing of veins. Mottling usually starts at the apex and progresses inwards. In addition, small almost circular chlorotic spots develop which tend to fade when greater portion of the leaf becomes chlorotic. The subsequent leaves also show vein clearing together with apical and marginal chlorosis. Some leaves exhibit severe blistering or puckering between the veins as in the case of bottle gourd, others show downward curling of leaf margin and apex.

In some plants, however, the first infected leaf may show vein clearing and excessive blistering between the veins but no chlorosis. The affected leaves do not show much distortion.

Repeated efforts to transmit the disease to solanaceous plants such as tomato (*Lycopersicum esculentum* Mill. var. Suttons' Early Market), Jimson weed (*Datura Stramonium* L.), pepper (*Capsicum annuum* L.), petunia (*Petunia hybrida* Vilm.) and tobacco (*Nicotiana tabacum* L. var. White Burley) were unsuccessful. In addition, cowpea [*Vigna unguiculata* (L.) Walp.], both black seeded and ordinary, and soybean (*Glycine hispida* Maxim.) remained free from any symptoms of the disease when inoculated with standard extract prepared from diseased bottle gourd leaves.

Properties of the virus

Longevity in vitro. Pure juice prepared from the diseased bottle gourd leaves was divided into several lots of 5 c.c. each in test tubes which were stored in the laboratory. Young healthy bottle gourd plants were inoculated with samples of the stored juice at intervals of 24, 48, 72 and 96 hours. The temperature of the laboratory ranged between 28° and 37°C. during the experimental period. The fresh juice was tested for its infectivity prior to storage. Controls were run side by side in each case by inoculating plants with the freshly extracted juice.

All the stored samples of the juice failed to infect and produce any symptoms of the disease showing thereby that within a period of 24 hours at laboratory temperature the juice is rendered non-infectious.

In a similar experiment pure juice was replaced by standard extract which was stored at laboratory temperature as well as at 20°C. for similar periods, i.e. 24 to 96 hours but in every case the extract failed to bring about infection,

In another experiment standard extract from diseased bottle gourd plants was stored at room temperature (20° to 23·3°C. during the day) from 2 to 24 hours and the stored extract tested on young bottle gourd plants. The results are given in Table II.

TABLE II

Effect of storage of virus at room temperature

Experiment	Storage period	Number of plants	
		Inoculated	Infected
I	Fresh standard extract . . .	2	2
	$2\frac{1}{2}$ hours	3	3
	$4\frac{1}{2}$,, ...	3	2
	6 ,, ...	4	0
	8 ,, ...	3	0
	24 ,, ...	2	0
II	Fresh standard extract . . .	3	3
	24 hours	3	0
	48 ,, ...	3	0
	72 ,, ...	3	0
	96 ,, ...	3	0

The results given above show that the standard extract is rendered innocuous after being stored for six hours at room temperature.

When the standard extract was stored at 5°C. for 24, 48, 72 and 96 hours it was observed that after 96 hours storage the extract failed to bring about infection. It partially retained its infectivity after 72 hours, and gave 100 per cent infection after 24 hours, storage.

Desiccation. The leaves of infected bottle gourd plants were dried at room temperature for a week and the extract prepared by grinding the leaf tissue which had previously been soaked in water in a pestle and mortar. To every gram of the dried material 2 c.c. of water was added. The crushed material was then pressed through muslin. The extract thus prepared failed to infect young bottle gourd plants.

Thermal inactivation. Standard extract prepared from young diseased leaves of bottle gourd was divided into six samples of 5 c.c. each in thin walled glass test tubes of uniform size and capacity. Samples of the standard extract were exposed to 45°, 50°, 55°, 60° and 65°C. for 10 minutes in a water-bath,

Care was taken that the portion of the tube containing the extract was completely immersed in water. The samples of extract immediately after exposure to the above temperatures were dipped in cold water. Bottle gourd plants (24 days old) were inoculated with the samples of extract thus exposed and with unheated extract which served as check. The results of a typical experiment are given in Table III.

TABLE III

Thermal inactivation of the virus

Exposure temperature °C.	Plants inoculated	Plants infected
Untreated check	4	4
45	4	4
50	4	1
55	4	1
60	4	0
65	4	0

The results given above show that the activity of the virus falls considerable when exposed to 50°C. whereas no infections are obtained with the virus exposed to 60°C. or higher. In 60° and 65°C. lots no symptoms of infection appeared even 31 days after inoculation.

Effect of chemicals. Effect of 50 per cent alcohol, acetone and chloroform on the standard extract prepared from diseased bottle gourd plants was determined by adding 5 c.c. of the above chemicals to 5 c.c. of the standard extract. Samples of extract thus treated and the untreated control to which 5 c.c. distilled water had been added were shaken for 10 minutes and young healthy bottle gourd plants inoculated with different samples. The inoculated plants were kept under observation for four weeks. Extracts treated with alcohol and acetone appeared to have lost their activity, as they failed to cause infection, whereas the control extract reproduced typical disease within 11 days. Bottle gourd plants inoculated with extract treated with chloroform produced a burning effect on the plants so that it was difficult to read the symptoms.

Inoculations of healthy bottle gourd plants with standard extract of diseased bottle gourd plants containing various strengths of mercuric chloride showed that the virus is inactivated by mercuric chloride in a strength of 1 : 5000. The results of such an experiment are given in Table IV.

Toleration to dilution. Leaves of young bottle gourd plants (15 days old) were inoculated with freshly extracted pure juice from diseased plant leaves as well as with juice diluted with sterilized distilled water in order to determine the effect of dilution on infectivity of the juice. The results of three typical experiments are set out in Table V.

TABLE IV

Effect of mercuric chloride on the activity of the virus

Strength of mercuric chloride	Number of plants	
	Inoculated	Infected
Nil (Standard extract full strength control)	6	6
Nil (Standard extract diluted with water 50 : 50 control)	6	6
1 : 10,000	6	5
1 : 5,000	5	0
1 : 2,000	6	0
1 : 1,000	4	0

TABLE V

Effect of dilution on infectivity

Dilution	Experiment I		Experiment II		Experiment III	
	Number of plants		Number of plants		Number of plants	
	Inoculated	Infected	Inoculated	Infected	Inoculated	Infected
Nil (control)	3	3	4	4	4	4
1 : 10	3	3	—	—	—	—
1 : 50	3	2	—	—	—	—
1 : 100	3	1	4	2	4	4
1 : 500	—	—	4	0	3	0
1 : 1,000	—	—	4	0	3	0
1 : 2,000	—	—	4	0	3	0
1 : 3,000	—	—	4	0	—	—
1 : 4,000	—	—	4	0	—	—
1 : 5,000	3	0	4	0	—	—
1 : 10,000	3	0	—	—	—	—

— denotes not tested

The results show that the virus is completely inactivated at and above dilutions of 1 : 500.

Filterability. Standard extract prepared from diseased bottle gourd plants was filtered through filter paper, filter paper impregnated with diatom dust and Pasteur Chamberland filters of grades L_1, L_3 and L_5. In the case of Chamberland filters the filtrations were always carried out under reduced pressure of 1/5 atmospheric. Infectivity of the filterates was tested on young healthy bottle gourd plants in the insect-proof house.

The experiment with each of the above filters was repeated at least three times. Typical results are recorded in Table VI.

TABLE VI

Filterability of bottle gourd virus

Experiment	Date	Inoculum	Number of plants	
			Inoculated	Infected
I	14 Aug. 1941	1. Unfiltered standard extract .	2	2
		2. Filtered standard extract—		
		(*a*) Filter paper (Whatman's 2) filtrate	4	1
		(*b*) Filter paper impregnated with diatom dust filtrate .	4	Nil
II	20 Aug. 1941	1. Unfiltered standard extract .	4	4
		2. Filtered standard extract—		
		(*a*) Filter paper (Schutz 613) filtrate	6	1
		(*b*) Chamberland Candle L_1 filtrate	4	Nil
		(*c*) Chamberland Candle L_3 filtrate	4	Nil
		(*d*) Chamberland Candle L_5 filtrate	2	Nil
III	11 Dec. 1941	1. Unfiltered standard extract .	3	3
		2. Filtered standard extract .		
		(*a*) Filter paper (Schutz 613) filtrate	6	Nil
		(*b*) Chamberland Candle L_1 filtrate	5	Nil
		(*c*) Chamberland Candle L_3 filtrate	5	Nil

The results given in Table VI show that the standard extract from infected bottle gourd plants during passage through filter paper loses a greater part of its active infective principle. The virus fails to pass through Chamberland filters of different grades, i.e. L_1 to L_5 and even through filter paper impregnated with diatom dust.

Transmission. Bottle gourd mosaic virus is readily transmissible by the sap. An experiment was conducted to find out whether the virus is transmissible through seed. A few young healthy bottle gourd plants growing in the insect-proof house were infected with the virus and transplanted in an open field when the infection had become systemic. The seeds of fruits borne by such plants were collected and sown in pots. Over 200 plants raised from seeds of diseased plant fruits appeared to be normal and remained free from any symptoms of the disease showing thereby that the transmission of the disease through seed does not occur.

From the observations recorded in this paper it is evident that bottle gourd mosaic is a virus disease and is readily transmissible by mechanical inoculation with sap. The host range of the virus appears to be narrowly restricted. The virus fails to pass through Chamberland filters or filter paper impregnated with diatom dust. Infectivity of the virus is lost within six hours when stored at room temperature (20°—23·3°C.). Exposure to 60°C.

for 10 minutes renders it non-infectious. The virus is completely inactivated at a dilution of 1 : 500. Inactivation of the virus is also brought about by 50 per cent alcohol or acetone in 10 minutes and by mercuric chloride in a strength of 1 : 5000.

Bottle gourd virus is similar to *Cucumis* virus 1 [Doolittle, 1920] regarding filterability through Chamberland filters and thermal-death-point but differs regarding its host range, longevity *in vitro* and dilution-end-point. The virus like *Cucumis* virus 2 [Bewley, 1926] is unable to infect solanaceous plants but differs from *Cucumis* virus 2 in all other important properties.

It is proposed to call the bottle gourd mosaic virus *Cucumis* virus 3 (Smiths' classification). The properties of the three viruses are compared in Table VII.

TABLE VII

Properties of the Cucumis viruses compared

	Cucumis virus 1	*Cucumis virus* 2	Bottle gourd virus
Longevity in vitro (room temperature)	72 to 96 hours	One year or longer	Six hours
Filterability (Chamberland filters)	Not filterable	Filterable	Not filterable
Thermal inactivation	60° and 70°C.	90°C.	60°C.
Dilution-end-point	1 : 10,000	Not recorded	1 : 500
Resistance to 50 per cent alcohol	Inactivated in one hour	Not inactivated in one hour	Inactivated in 10 minutes
Infection of solanaceous plants	+	—	—
Infection of cowpea	+	—	—
Infection of vegetable marrow	+	—	+

+ = positive — = negative

SUMMARY

A new virus disease of bottle gourd (*Lagenaria vulgaris* Ser.) is described.

The virus has a limited host range and is highly sensitive so much so that storage for six hours at room temperature renders it innocuous. The virus loses infectivity at a dilution of 1 : 500 and exposure to 60°C. for 10 minutes is sufficient to destroy the infective principle. The virus is held back during passage through Chamberland filters and its infectivity is greatly impaired during passage through filter paper. It is proposed to call the virus *Cucumis virus* 3.

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STUDIES ON THE COTTON JASSID (*EMPOASCA DEVASTANS* DISTANT) IN THE PUNJAB

III. EFFECT OF JASSID INFESTATION ON THE DEVELOPMENT AND FIBRE PROPERTIES OF THE COTTON PLANT*

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In the previous two publications of this series [Varma and Afzal, 1940 and Afzal, 1941] the development of the pest on different varieties of cotton and the methods used in breeding resistant varieties were discussed. It is now proposed to examine in some detail the effect of jassid attack on the cotton plant.

Literature on this aspect of the problem is very scanty. We have been able to find only two references on this subject. The first one is that of Parnell [1925-26] who mentions in general terms that 'with the reddening of the plant, development ceases, squares and very young bolls are shed, partly developed bolls dry up and only those that are nearing maturity ripen off and open naturally. A certain proportion of the latter always produces weak lint, due to their development having been arrested at too early a stage'. Sloan [1938] also mentions the retardation of plant development and shedding of buds and young bolls with the jassid attack. 'Immature bolls develop poorly and produce wasty lint......In a mild outbreak......the quality of lint is not as good as that from uninfested plants'. Figures are not, however, given by either of the authors and it is difficult to picture the extent of the damage done to the plant. It was, therefore, considered necessary to assess the extent of damage done by jassids to the development and the fibre properties of the cotton plant grown at Lyallpur.

Material and methods

This study was carried out by growing plants in jassid-proof cages. As the number and size of cages was limited, in the beginning only a few plants of one variety could be grown in one year. During 1940, however, more and bigger cages were employed and the number of varieties and plants under experiment were consequently increased.

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Part II read at the 2nd Conference of the Scientific Research Workers on Cotton in India, I. C. C. C., January 1941

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During 1938, six plants of 38F, a highly susceptible variety of Punjab-American cotton, were raised in each of the two cages. One cage was kept free of infestation and in the other a very high degree of infestation was maintained throughout the season by artificially liberating a large number of jassid nymphs. During 1939, the same procedure was adopted for a highly resistant variety, namely P-A 289F/43. The only difference was that this year four plants were grown in each cage. The size of the cages in these two years was 6 ft. × 6 ft. × 6 ft. During 1940, the experiment was repeated with two susceptible (38F and 289F/K.25) and two highly resistant (289F/43 and L.S.S) varieties of Punjab-American cotton. Four plants of each of these varieties were grown in jassid proof cages (6 ft. × 6 ft. × 6 ft.) and kept free of any attack while about 20 plants of these varieties were grown in other cages (size 16 ft. × 16 ft. × 8 ft.) where the infestation was kept up artificially as before. Since these latter cages were much bigger than the jassid proof cages they may have proved of some advantage to the plants grown in them The plan of the experiment is given in Table I.

TABLE I

Plan of the experiment

Year	Variety	Resistant or susceptible to jassids	Number of plants in	
			Cage kept free of infestation	Cage infested with jassids
1938	38F . . .	Susceptible .	6	6
1939	P-A 289F/43 .	Resistant . .	4	4
1940	38F . . .	Susceptible .	4	21
	P-A 289F/43 .	Resistant . .	4	21
	P-A 289F/K.25	Susceptible .	4	22
	P-A L.S.S .	Resistant . .	4	20

Sowing was done towards the end of May each year and both the cages were treated alike for all cultural operations. Artificial infestation was started from about the middle of July and continued up to about the end of October each year and a jassid population of about 200 to 300 nymphs per plant was maintained throughout this period.

Records of weekly growth in height of the main stem and the daily rate of flower and boll production were maintained during 1938 and 1939. No such data are available for 1940. The produce of each plant was picked

and ginned separately for each year and the ginning outturn was calculated. The fibre properties were also determined.

The various records will now be dealt with in detail, but it should be mentioned at the very outset that as the plant population was small, the experimental error may be expected to be high. The very high cost of jassid proof cages did not allow us to deal with a larger number of plants. In the case of development records a further drawback arose in that data for only two years were available.

Results

Growth in height

The weekly growth in height of both the varieties in the infested and the jassid-free cages was measured. The figures along with their statistical interpretation are given in Table II.

Although the records on the susceptible and the resistant varieties were taken in two different years, yet certain interesting deductions could be made from Table II. By applying the equation $H = Ae^{bt}$ [Afzal and Iyer, 1934], we find that the relative rate of growth 'b' was significantly smaller in the infested plants of the susceptible variety (38F) than in those kept free while in the case of the resistant variety (289F/43) there was no such difference. Thus it will be seen that whereas a heavy infestation of jassids on a susceptible variety significantly reduced its rate of growth, an apparently equally high infestation on a resistant variety had no such effect. It must, however, be stressed that the ideal plan would have been to perform these experiments on the susceptible and the resistant varieties in the same season. Since the two varieties were grown in two different years, the effect of the seasonal factors cannot be easily brought out.

Flower and boll production

The flower and boll counting was done every day and the results are summarized in Table III.

Here again it will be seen that the differences in the number of flowers and bolls produced in the case of infested and free plants of the susceptible variety were statistically significant ; the infested plants produced a definitely smaller number of flowers and bolls than those kept free of attack. In the case of the resistant variety, on the other hand, there was no significant difference in the number of flowers and bolls produced by the infested and the free plants. The difference in the shedding percentage of bolls was non-significant in both the cases.

The *kapas* (seed cotton) picked from each plant was weighed and ginned separately and the average weight of *kapas* per boll and the ginning outturn were determined in each case. It will be seen from Table III that in the case of the susceptible variety, although there was no statistical difference in the average weight of *kapas* per boll, the shedding percentage and the ginning outturn of the infested and the free plants, the total amount of *kapas* per plant was, however, significantly more in the free plants. In the case of the resistant variety there was no such difference in any of these three characters between the infested and the free samples.

TABLE II

Average increase in height (cm.) of infested and free plants in 1938 and 1939

Week ending	1938-Variety-38F susceptible to jassids Average for plants in cage		1939-Variety-289F/43 resistant to jassids Average for plants in cage	
	Free	Infested	Free	Infested
Initial height on— July 5	14·8	20·9	66·1	54·9
July 12	8·9	6·6	..	..
July 18	13·5	8·1	..	..
July 25	13·0	7·5	14·5	14·8
August 1	11·2	6·6	9·0	6·2
August 8	11·4	5·4	13·6	7·5
August 15	10·3	5·8	14·8	7·7
August 22	11·4	4·5	14·1	4·3
August 29	11·8	5·0	12·5	7·8
September 5	17·0	8·3	8·6	12·3
September 12	16·5	13·4	10·9	12·3
September 19	9·1	9·7	9·0	5·5
September 26	8·7	6·4	8·8	4·1
October 3	13·4	11·2	4·7	1·4
October 10	6·7	8·4	..	..
October 17	7·3	3·3	..	..
Mean	11·35	7·35	10·95	7·63
Total height attained (cm.)	185·0	131·1	186·6	138·8
Equation [$H = Ae^{bt}$]	$23{\cdot}35e^{0{\cdot}1499t}$	$24{\cdot}76e^{0{\cdot}1140t}$	$69{\cdot}07e^{0{\cdot}0928t}$	$58{\cdot}05e^{0{\cdot}0811t}$
Relative growth rate 'b'	0·1499	0·1140	0·0928	0·0811
S. E. of 'b'	±0·01386	±0·006242	±0·006678	±0·005293

TABLE III

Flower and boll production

Nature of infestation	Plant No.	1938—Susceptible variety (38F) Total No. of flowers	Total No. of bolls	Shedding per centage	Average weight of *kapas* per boll (gm.)	Total weight of *kapas* (gm.)	Ginning outturn	1939—Resistant variety (289F/43) Total No. of flowers	Total No. of bolls	Shedding per-centage	Average weight of *kapas* per boll (gm.)	Total weight of *kapas* (gm.)	Ginning outturn
Infested—													
	1	38	7	81·5	2·23	15·6	26·9	36	6	83·3	3·05	18·30	26·50
	2	27	7	74·0	2·44	17·1	26·3	31	4	87·1	2·68	10·72	27·93
	3	43	10	76·7	1·95	19·5	25·7	14	4	71·4	2·04	8·17	29·49
	4	28	4	85·7	4·08	16·3	23·9	43	7	87·7	2·84	19·9	29·54
	5	49	9	81·6	3·24	29·2	28·4	...	...	...	...	...	...
	6	18	5	72·2	3·64	18·2	23·6	...	...	...	...	...	...
Free—													
	1	55	11	80·0	2·98	32·8	27·5	59	11	81·3	2·55	28·08	27·77
	2	65	12	81·5	2·24	26·9	24·9	26	8	69·2	2·67	21·39	26·22
	3	85	23	72·9	2·88	66·3	26·9	20	7	65·0	2·88	20·16	27·13
	4	53	19	64·1	3·17	60·4	27·4	20	6	70·0	2·59	15·54	32·49
	5	50	14	72·0	2·27	31·8	28·1	...	...	...	...	...	...
	6	76	19	76·0	3·35	63·7	29·8	...	...	...	...	...	...
Difference of means		+30·17	+9·33	—4·20	—0·115	+27·66	+1·63	+0·25	+2·75	—11·00	+0·020	+7·02	+0·038
Value of '*t*'		4·072*	4·361*	1·263	0·291	3·576*	1·646	0·022	2·0913	2·138	0·087	1·822	

* Indicates significance at 1 per cent level

Fibre properties

From the 1938 experiment, 12 samples of lint of 38F, six from the control and six from the infested cages were available for tests for fibre characters. In 1939, there were 8 samples of lint of P-A 289F/43, four from the control cage and four from the infested one. In 1940, whereas samples of lint from 4 plants each of the Punjab-American varieties: 38F, 289F/K.25, 289F/43 and L S.S., from the control cages were available, the number of samples of lint available from the cages infested with jassids were 21 from 38F, 22 from 289F/K.25, 21 from 289F/43 and 20 from L.S.S. (Table I). The disparity in the numbers of samples from the control and infested cages was too high and, to reduce this disparity, lots were drawn choosing perfectly at random six samples from the infested cage in each of the above-mentioned four varieties.

All these samples were tested for the following fibre-characters.

(*a*) Mean fibre length
(*b*) Modal length
(*c*) Fibre-length irregularity (per cent)
(*d*) Mean fibre-weight per unit length
(*e*) Percentage of mature fibres, and
(*f*) Highest standard warp counts.

The methods followed in the determination of the first four characters were the same as described by Ahmad [1933] and in the determination of the percentage of mature fibres, the method of Gulati and Ahmad [1935] was adopted using their new device for mounting fibres [Ahmad and Gulati, 1936]. The first five fibre-characters were converted into a quantity highest standard warp count (H.S.W.C.) according to an equation given by Ahmad [1941]. The H.S.W.C. serves to indicate in a single term the spinning quality of a cotton. However, as in the present case, it was not determined as the result of actual spinning tests but was calculated from the fibre-properties, the value obtained should be ragarded as approximately correct. These data are presented in Table IV.

The differences in the average values of fibre-characters of samples of lint from the control and the jassid-infested cages were examined for statistical significance by the Student's '*t*' method [Fisher, 1932]. The average values of fibre-characters in samples from the control and jassid-infested cages, the differences between them, the corresponding '*t*' values and their significances are brought out in Table V.

In the case of 38F, a variety highly susceptible to attack by jassids, it was found in t' e 1938 experiment that the mean and modal lengths in samples from the jassid-infested cage were significantly lower than those in samples from the control cage. The fibre-length irregularity was similarly higher in samples from the infested cage. The mean fibre-weight per unit length and percentage of mature fibres were not significantly different from one another even though the samples from the control cage recorded uniformly higher values for these characters. The calculated H.S.W.C. in samples from the control cage was significantly greater than in samples from the infested cage. On the whole, it could be stated that the quality of lint in samples from the control cage was better than that in the infested cage.

TABLE IV

Year	Variety	Control cage							Infested cage						
		Plant No.	Mean fibre-length (cm.)	Modal length (cm.)	Fibre-length irregularity (per cent)	Mean fibre-weight per unit length 10^{-6} gm./cm.	Percentage of mature fibres	H.S.W.C. (calculated)	Plant No.	Mean fibre-length (cm.)	Modal length (cm.)	Fibre-length irregularity (per cent)	Mean fibre-weight per unit length 10^{-6} gm./cm.	Percentage of mature fibres	H.S.W.C. (calculated).
1938	P-A 38F .	1	2·55	2·92	20·9	1·69	58	44·1	1	2·30	2·65	23·5	1·77	48	35·6
		2	2·35	2·68	23·2	1·34	23	39·9	2	2·34	2·66	24·8	1·63	55	38·9
		3	2·52	2·95	23·0	1·70	61	44·8	3	2·19	2·37	25·4	1·30	41	36·5
		4	2·49	2·81	21·2	1·72	59	42·3	4	2·35	2·62	24·1	1·53	49	39·9
		5	2·33	2·63	23·2	1·42	50	40·7	5	2·39	2·72	24·7	1·69	66	40·1
		6	2·42	2·72	19·6	1·67	50	40·4	6	2·30	2·66	25·5	1·54	41	37·7
1939	P-A 289F/43 .	1	2·50	2·72	17·6	1·64	63	45·0	1	2·53	2·88	22·5	1·99	71	41·3
		2	2·43	2·72	25·4	1·53	43	41·3	2	2·42	2·70	24·9	1·55	52	41·9
		3	2·50	2·74	21·6	1·46	36	43·7	3	2·37	2·60	20·1	1·47	49	41·0
		4	2·33	2·45	17·3	1·60	47	38·3	4	2·54	2·75	18·6	1·64	59	44·7
1940	P-A 38F .	1	2·07	2·20	25·8	1·56	57	32·1	2	2·15	2·19	22·9	1·62	43	32·1
		2	2·23	2·44	24·3	1·93	76	33·7	3	2·12	2·22	23·7	1·56	36	31·9
		3	2·25	2·50	25·2	1·90	76	34·6	6	1·89	1·87	18·4	1·46	39	26·7
		4	2·19	2·23	21·3	1·88	78	33·2	13	2·11	2·21	23·0	1·77	55	30·3
									18	2·11	2·22	23·4	1·71	47	30·4
									21	1·97	1·92	15·8	1·67	67	28·5
1940	P-A 289F/K.25	1	2·12	2·25	23·9	1·71	58	31·9	2	2·20	2·46	23·7	1·90	55	31·5
		2	2·24	2·48	26·4	1·67	49	35·0	9	1·97	2·09	16·1	1·93	44	22·7
		3	2·43	2·80	26·5	1·73	53	40·1	12	2·09	2·25	27·7	1·36	26	33·2
		4	2·30	2·61	21·6	1·55	43	37·3	13	2·02	2·14	24·6	1·43	26	28·8
									15	2·22	2·45	23·9	1·52	48	36·5
									22	1·89	1·89	16·4	1·20	6	26·0
1940	P-A 289F/43 .	1	2·40	2·74	29·8	1·37	34	42·3	3	2·49	2·77	22·7	1·62	52	42·9
		2	2·37	2·71	25·2	1·66	47	38·9	5	2·53	2·83	26·3	1·66	45	43·5
		3	2·22	2·47	26·7	1·85	46	32·2	6	2·40	2·66	25·7	1·87	57	37·8
		4	2·24	2·30	21·9	1·43	39	37·0	15	2·42	2·69	26·9	1·77	58	39·7
									19	2·50	2·85	26·0	1·84	66	41·9
									23	2·11	2·21	21·5	1·78	49	31·6
1940	P-A L.S-S. .	1	2·28	2·60	25·0	1·50	47	37·3	1	2·18	2·40	19·9	1·73	55	33·1
		2	2·34	2·61	22·7	1·69	53	37·7	2	2·28	2·52	19·3	1·90	79	35·6
		3	2·20	2·44	25·6	1·18	13	37·0	5	2·20	2·38	18·0	2·08	69	30·4
		4	2·17	2·37	22·6	1·52	35	33·8	16	2·37	2·62	20·3	1·62	56	39·9
									19	2·04	2·22	13·7	1·82	51	27·5
									20	2·27	2·56	23·6	1·63	42	35·5

TABLE V

Variety	Fibre-character	Infested cage		Control cage		Difference in average values (Col. 4—col. 6)	D. F.	't'	Infested cage		Control cage		Difference in average values (Col. 11—col. 13)	D. F.	't'
		No. of samples	Average value	No. of samples	Average value				No. of samples	Average value	No. of samples	Average value			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		1938							1940						
P-A 38F	Mean fibre-length (cm.)	6	2·31	6	2·44	—0·13	10	2·825*	6	2·06	4	2·18	—0·13	8	2·052
	Modal length (cm.)	6	2·61	6	2·79	—0·18	10	2·370*	6	2·10	4	2·34	—0·24	8	2·318*
	Fibre-length irregularity (per cent)	6	24·6	6	21·8	+2·8	10	4·070†	6	21·2	4	24·1	—2·9	8	1·589
	Mean fibre-weight per unit length (10^{-6} gm./cm.)	6	1·58	6	1·59	—0·01	10	0·137	6	1·63	4	1·82	—0·19	8	2·094
	Percentage of mature fibres	6	49·9	6	50·3	—0·4	10	0·060	6	47·8	4	71·7	—23·9	8	3·393†
	Highest standard warp counts (calcu ated)	6	38·1	6	42·0	—3·9	10	3·488†	6	30·0	4	33·4	—3·4	8	3·014*
		..							1940						
P-A 289F/K. 25	Mean fibre-length (cm.)								6	2·06	4	2·27	—0·21	8	2·480*
	Modal length (cm.)								6	2·21	4	2·53	—0·32	8	2·217
	Fibre-length irregularity (per cent)								6	22·1	4	24·6	—2·5	8	0·980
	Mean fibre-weight per unit length (10^{-6} gm./cm.)								6	1·56	4	1·66	—0·11	8	0·700
	Percentage of mature fibres								6	34·2	4	50·8	—16·6	8	1·728
	Highest standard warp counts (calculated)								6	29·8	4	36·1	—6·3	8	2·169

N.B.—* Indicates significance at 5 per cent level
† Indicates significance at 1 per cent leve

TABLE V—*contd.*

Variety	Fibre-character	Infested cage: No. of samples	Infested cage: Average value	Control cage: No. of samples	Control cage: Average value	Difference in average values (Col. 4—col. 6)	D. F.	't'	Infested cage: No. of samples	Infested cage: Average value	Control cage: No. of samples	Control cage: Average value	Difference in average values (Col. 11—col. 13)	D. F.	't'
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		1939							1940						
P-A 289F/43	Mean fibre-length (cm.)	4	2·46	4	2·44	+0·02	6	0·381	6	2·41	4	2·31	+0·10	8	1·164
	Modal length (cm.)	4	2·73	4	2·66	+0·07	6	0·829	6	2·67	4	2·55	+0·12	8	0·775
	Fibre-length irregularity (per cent)	4	21·5	4	20·5	+1·0	6	0·445	6	24·8	4	25·9	—1·1	8	0·612
	Mean fibre-weight per unit length (10^{-6} gm./cm.)	4	1·66	4	1·56	+0·10	6	0·865	6	1·76	4	1·58	+0·18	8	1·780
	Percentage of mature fibres	4	57·7	4	47·2	+10·5	6	1·390	6	54·5	4	41·5	+13·0	8	2·882*
	Highest standard warp counts (calculated)	4	42·2	4	42·1	+0·1	6	0·088	6	39·6	4	37·6	+2·0	8	0·699
		......							1940						
P-A. L.S.S.	Mean fibre-length (cm.)								6	2·22	4	2·25	—0·024	8	0·372
	Modal length (cm.)								6	2·45	4	2·50	—0·05	8	0·625
	Fibre-length irregularity (per cent)								6	19·1	4	24·0	—4·8	8	2·740*
	Mean fibre-weight per unit length (10^{-6} gm./cm.)								6	1·80	4	1·47	+0·32	8	2·633*
	Percentage of mature fibres								6	58·7	4	37·0	+21·7	8	2·236
	Highest standard warp counts (calculat. d)								6	33·7	[illegible]	36·4	—2·8	8	1·192

N.B.—*Indicates significance at 5 per cent level

Repeating the experiments in 1940, it was found that the mean fibre-length in samples from the control cage was higher than in samples from the infested cage, though the '*t*' value of the difference in the two average values was just a little lower than that for the 5 per cent level of significance. The trend of the difference being in the same direction as in 1938, this difference can also be considered as significant. The modal length and percentage of mature fibres of samples from the control cage were significantly greater than in samples from the infested cage and the mean fibre-weight per unit length was higher in the control cage than in the infested one, the '*t*' value of the difference in this case also being just lower than that for the 5 per cent level of significance. The fibre-length irregularity percentage was not significantly different in samples from the control and infested cages. The calculated H.S.W.C. in samples from the control cage was significantly higher than that in samples from the infested cage. The above study leads, therefore, to the conclusion that in P-A 38F, highly susceptible to jassid attack, the quality of lint deteriorates significantly due to attack by jassids.

This observation was further corroborated by the study in 1940 of the fibre-characters of P-A 289F/K. 25, also highly susceptible to attack by jassids. The mean fibre-length in samples from the infested cage was significantly lower than in samples from the control cage and the modal length also was lower in the infested than in the control cage, though the '*t*' value of the difference in this case was slightly lower than that for the 5 per cent level of significance. The trend of the difference being in the same direction as in the case of 38F, this difference can also be considered as significant. The fibre-length irregularity percentage, the mean fibre-weight per unit length and the percentage of mature fibres were all higher in samples from the control cage than in those from the infested one, even though the differences in the averages were not statistically significant. The calculated H.S.W.C. was higher in samples from the control cage than in those from the infested one. The '*t*' value of the difference in the averages, being in this case also slightly less than that for 5 per cent level of significance, can again be treated as significant. It may, therefore, be concluded that, on the whole, a variety, susceptible to jassids, suffered a deterioration in the quality of its lint by an attack of jassids.

In both the years, 1939 and 1940, in which the highly resistant variety, P-A 289F/43, was under study, no significant difference was observed in respect of any of the six fibre characters studied in the samples of lint from the control and infested cages, excepting the percentage of mature fibres, which in 1940, was significantly higher for samples from the infested cage than for samples from the control cage. It might also be pointed out that in both the years, the mean fibre-length, modal length, mean fibre-weight per unit length and percentage of mature fibres were higher, though not significantly, in samples from the infested cage than in those from the control cage. This is contrary to what should ordinarily be expected in view of the conclusions arrived at in the previous two cases of susceptible varieties. It could be stated, therefore, that the P-A 289F/43, resistant to jassids, suffered no deterioration in its lint quality in spite of an intense infestation with jassids.

This conclusion, in respect of the jassid resistant variety, P-A 289F/43, was borne out by the study in 1940 of the fibre-characters of P-A L.S.S., a variety

also jassid resistant. The average values of mean fibre-length, modal length and calculated H.S.W.C. were not significantly different in samples from the control and infested cages. The fibre-length irregularity percentage was significantly higher in samples from the control cage and the mean fibre-weight per unit length similarly lower in samples from the control cage ; the percentage of mature fibres was lower in samples from the control cage than in those from the infested cage, the 't' value for the difference in the average of this fibre-character being just short of that for the 5 per cent level of significance. The mean fibre-weight per unit length and percentage of mature fibres were, quite contrary to what should ordinarily be expected, higher in samples from the infested cage than in those from the control cage. In the case of P-A L.S.S. also as in the case of P-A 289F/43, both varieties resistant to jassids, a severe infestation with jassids produced no deterioration in lint quality.

No suitable explanation can be suggested for the very slight improvement of lint quality under severe jassid infestation in the case of both the resistant varieties (289F/43 and L.S.S.). It must, however, be made clear that no improvement in lint quality may be expected as a result of jassid attack on the resistant varieties under the general agricultural conditions.

Discussion

The present investigations on the effect of jassid attack on the development of the cotton plant and its fibre properties have revealed a very important phenomenon in that the effect of high infestation did not seem to interfere with the fibre properties and development of the plant of a resistant variety under Lyallpur conditions. In the case of a susceptible variety, on the other hand, both the development and the fibre properties were seriously interfered with by jassid infestation. Such a differential behaviour of the susceptible and resistant variety has, so far as we are aware, not hitherto been recorded. Although the growth and flowering records were taken on the susceptible and the resistant varieties in two different years, the seasonal variations alone were not probably the main factors responsible for the observed differences in the two varieties.

It must here be mentioned that the external symptoms of jassid attack—crinkling and reddening of the leaves—were quite pronounced even when the resistant varieties were under experiment. This showed that the drain on the cell sap was quite appreciable, but these varieties were able to tolerate this drain much better than the susceptible varieties.

It has always been stressed that no variety of American cotton should be released for general cultivation by the Punjab Department of Agriculture, unless its resistance to jassids has been fully tested. That this is a very sound policy is now further proved by the present investigations. The presence of jassids in quite large numbers has sometimes been observed in tracts where the resistant varieties have been sown, almost to the exclusion of any other variety and doubts have sometimes been expressed that these cottons, although resistant under normal conditions, might suffer in abnormal years when the jassids were present in large numbers. The causes which lead to the prevalence in large numbers of jassids in certain years and their virtual absence in others have not so far been elucidated, but the present investigations

have shown that the risk of deterioration, both in quality and quantity, is reduced if the cultivator resorts to sowing the resistant varieties recommended by the Punjab Department of Agriculture.

Summary

The effect of a heavy jassid infestation has been studied both on resistant and susceptible varieties of Punjab-American cottons.

It has been shown that a heavy jassid infestation has been instrumental in reducing the growth in height of the main stem, number of flowers produced, number of bolls opened and the total weight of *kapas* per plant in the case of suscepting varieties while no such ill effects were noticed in the case of a resistant variety.

In both the varieties, 38F and 289F/K.25, highly susceptible to jassids, the quality of lint suffered, in general, a deterioration by a heavy infestation of jassids. The mean fibre-length of both the varieties was lowered significantly by the infestation, while the mean fibre-weight per unit length and percentage of mature fibres also recorded a reduction, though not statistically significant.

In P-A 289F/43 and L.S.S., both varieties resistant to jassids, no significant deterioration was observed in any of the fibre-characters studied and, hence, in lint quality in general, in spite of a heavy infestation of jassids.

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STUDIES ON PRECISION OBSERVATIONS ON RICE AT KARJAT

BY

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WITH A PREFACE

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PREFACE

ONE of the first tasks of the Section of Agricultural Meteorology at the Meteorological Office, Poona, soon after its formation in 1932, was to examine the yield data available at the experimental farms in India and if possible to correlate them with weather factors. A preliminary examination of the data showed that in most of the experimental farms in India attention had been confined so far to manurial and varietal experiments and that even yield data falling under the category of what may be called 'farm averages', where the yields of all varieties and treatments are lumped together and averaged, were then available only for periods up to 10 or 15 years. The only place where data relating to the same variety and similar treatment were available for a comparatively long series of years was the Cawnpore Experimental Farm where experiments on wheat [Kalamkar and Singh, 1935] had been in progress continuously during the period 1885—1913.

About this time the Agricultural Meteorology Committee in Great Britain under the leadership of Prof. R. A. Fisher had conceived the idea of collecting what has been called 'precision observations' on wheat by applying the new methods of random sampling. The observations aim at tracing the entire life-history of the crop from the date of sowing to the date of harvest together with the variations in the climatic environment of the crop during the season at a selected number of centres for a series of years. An account of this work wi l be found in [Russell and Watson, 1940] Technical Communication No. 40 of the Imperial Bureau of Soil Sciences.

In India we decided to develop the sampling technique suitable for some of the important crops on the lines of the British scheme. Short crops like wheat and rice were experimented with during the last few years while work on the taller crops like *jowar* and sugarcane has been started a couple of years ago. In work of this nature an initial period of experimentation and trial is absolutely essential for deciding upon a final and satisfactory procedure for estimating the growth and yield of different crops. It may be said that so far as short crops like wheat and rice are concerned the 'initial' period is almost over; with regard to the tall crops we are still passing through that period. During the next few years when the preliminary work is completed we shall be in a position to fix the most suitable sampling technique for different crops.

This work has now assumed a certain amount of urgency and importance in view of the fact that agricultural institutions and workers in India are realizing that the old methods of crop estimation will have to give way before the modern objective methods. At a recent meeting (February 1942) of the Board of Agriculture and Animal Husbandry in India one of the important subjects discussed was the need for starting of weather and crop observations on a systematic basis at a number of centres representative of the important crops of the country. We are thus faced with the problem of laying the foundations in India of sound crop and weather statistics.

The present paper deals with the precision observations on rice recorded at Karjat during the last few years according to a scheme prepared by the Agricultural Meteorology Section at Poona. Dr B. S. Kadam, the Crop Botanist to the Government of Bombay, was very enthusiastic in arranging for these observations at Karjat and his cooperation has been invaluable. Dr R. J. Kalamkar was responsible for the scrutiny of the data and the guidance of the computors up to 1937 ; later this side of the work was continued by Messrs. V. Satakopan and S. Gopal Rao. The introduction dealing with the general geographical and agricultural features of the Karjat area has been contributed by Dr Kadam. The investigation is an example of healthy cooperation between the Crop Botanist to the Government of Bombay (Dr Kadam) and the workers on agricultural meteorology at Poona. *The paper is the result of team work in which all the authors have contributed more or less equally.*

In concluding this preface I must record my grateful thanks to the Director of Agriculture, Bombay Province, for the cooperation extended through Dr Kadam and to Dr C. W. B. Normand, Director General of Observatories, for his keen interest in the progress of these pioneer investigations.

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INTRODUCTION

RICE is the third important staple crop in the Bombay presidency. Its cultivation extends from one end of the province to the other and is confined mostly to the coastal areas. Compared to the major rice-producing provinces, the acreage in the Bombay presidency is very small, being only 20,00,000 acres. This area produces roughly 8,00,000 tons of rice, an amount which is insufficient to meet the entire demand of local consumption. Bombay is therefore a deficit province, and has been depending mostly on Madras and Burma to supplement the local production of rice.

Although the aggregate acreage under rice in the province is small, it is distributed over a length of 640 miles, thus presenting extraordinary variations of soil, climate, varieties and agricultural practices. The whole area, therefore, groups itself into distinct zones. These are (1) Gujarat, (2) North Konkan, (3) South Konkan, (4) Maval, (5) Malnad, and (6) Kanara. In view of the variety of conditions in which the rice crop has to grow the Department of Agriculture in Bombay has devoted considerable attention to the genetic improvement of this crop. At present there is a string of five rice-breeding stations throughout the length of the province and it is contemplated to add three more stations in the near future.

The most important rice-growing zone, from the point of acreage and export of local rices, is north Konkan. It comprises the districts of Thana and Kolaba and Bombay suburban districts. The first rice-breeding station was opened at Karjat in the Kolaba district in the year 1919. This station has developed a large number of improved strains from the famous Kolamba rice. These are now spreading very extensively in the north-Konkan zone. The Rice Breeding Station at Karjat is the premier station in the province and has devoted also considerable attention to ancillary problems concerning rice cultivation. Our studies were conducted at this station. In order that the reader may gain a proper perspective of the general rice cultivation in this part of the province of Bombay, a brief description of the environment and cultural methods of rice cultivation is presented here.

Climate and rainfall. There are four distinct seasons. The cold season is from November to March. During this period the temperature at Karjat during the day varies from 61° F. in the morning to 95° F. in the afternoon. The cold spell is followed by the hot weather, lasting from April to June. During these months the temperature often touches the 116°F. mark. The heat is very oppressive. The month of April is the hottest.

The onset of the monsoon in June brings the long awaited relief from the summer heat. The rainy season lasts up to the end of September, and in some years extends into the month of October. During this month the weather is damp and very hot.

The rainfall in the district varies from 90 to 150 in., heavier rainfalls being confined to the foot of the hills of the Western Ghats. The months of July and August are the wettest receiving over 64 per cent of the total rainfall. The average rainfall for the period 1931-40 is 138 in. at Karjat. The distribution of rainfall is very important during the growing period of the paddy crop.

Soils. The rice soils in the north Konkan are derived from trap and are mainly of two kinds. The high-lying shallow and reddish types of soils support earlier ripening varieties of rice, and when the soils are very poor they give way to lesser millets such as *vari* or *nachani*.

The heavier rice soils are situated at a lower level, usually in the valleys or the plains. These soils are blackish or dark brown in colour. Being more retentive of moisture they are suitable for mid-late and late varieties of rice. The upper layers of these soils receive washings from the hills or uplands. In depth, therefore, the soils vary from 6 to 18 inches. The upper layer is overlaid on *murum* or disintegrated rock ; hence the drainage is very good.

Soils in north Konkan are generally considered deficient in nitrogen, but have sufficient supplies of potash, phosphoric acid and other minerals to support normal growth of rice.

Methods of cultivation of rice. Throughout north Konkan, rice is grown as a cultivated and as a transplanted crop except when grown on salt lands and in summer. Seedlings required for transplanting are raised in nurseries with specially prepared seed beds. Throughout the off season the farmers prepare these beds which are carefully covered with layers of dry cowdung pieces and litter of dry leaves and branches and dry grass. The whole is fired some time before the month of June, leaving a friable seed bed. After this, the cultivator waits for the first showers of rain. With the setting in of the monsoon, in the beginning of June, rice seed is broadcasted and mixed in with the soil by light

ploughing. Sometimes the farmers sow seed in dry seed-beds before any rains are received.

Under normal conditions, seedlings are ready for transplanting in three to four weeks. The seedlings are transplanted in bunches of 10 to 15 seedlings in well-puddled fields. The bunches are set at random, but the distance usually varies from 9 to 12 in. and even up to 18 in. in very heavy soils. It takes about a fortnight for the new crop to set in. After this period weeding is usually done.

The early crops commence to flower during the month of September, while the late ones do so in the beginning of October. Flowering is a critical period in the life of the plants and if it rains heavily at this time the filling of the grains is affected. The grain matures in three to four weeks, the earlier varieties requiring a little longer time than the late ones, as later in the season the temperature being higher the crop ripens faster.

The early varieties ripen in October and the late varieties in November. The crop is harvested by hand and laid up in sheaves. It is allowed to remain in the fields for about two days and then gathered up in bundles. The bundles are carried to the threshing yard and stocked with ears towards the centre of the stack. The top of the stack is covered up with straw or some other material in such a way that rain water runs off easily. The stacks are built on a wooden or earthen platform.

The crop is threshed in small bundles by striking against a wooden bench. Rice grain separates easily and a few strokes suffice to loosen all the grain from the bundle. If the variety is hard to thresh, the grain is separated by treading under bullock's feet. The grain is dried well for storing.

The yield of rice varies considerably from tract to tract since soil and season, variety and intensity of cultivation play an important part in determining the yield. Early varieties usually give an outturn ranging from 1000 to 1800 lb. while late varieties usually yield 2000 to 3200 lb. per acre.

Precision observations on rice

Sampling technique 1934

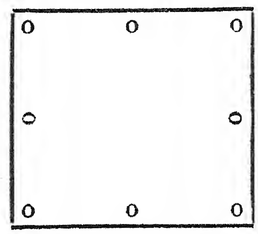
For the purpose of observing the developmental characters of the crop by sampling, a plot of land at the Rice Breeding Station at Karjat 70 ft. × 50 ft. was marked out in 1934 and divided into five blocks. Each block was divided into two plots and each plot was further divided into two sub-plots of 7 ft. × 25 ft. each. One plot in each block was transplanted with regular lines with eight seedlings per bunch, the distance between the bunches being 1 foot. The other plot in the block was transplanted according to the cultivator's method where the number of seedlings per bunch and also the spacing of the bunches varied. The observations were taken in both plots this year.

Sampling for regular planting. Each sub-plot with regular planting had seven rows of 25 bunches each, giving 175 bunches in all. Out of the seven rows three were chosen at random and from each row a sampling unit of eight bunches was selected. The sampling unit consisted of four pairs of adjacent bunches separated by three bunches in between as indicated below—

$$\mathrm{O\,O}\underbrace{\mathrm{X\,X\,X}}_{\text{Omit}}\mathrm{O\,O}\underbrace{\mathrm{X\,X\,X}}_{\text{Omit}}\mathrm{O\,O}\underbrace{\mathrm{X\,X\,X}}_{\text{Omit}}\mathrm{O\,O}$$

The observations were made on these eight bunches.

Sampling for irregular planting. In the case of irregular planting a frame three feet square was used and eight bunches nearest to the four corners and the four mid-points of the sides of the frame formed a sampling unit as indicated below. The location of the frame inside the plot was fixed by randomization. Three such samples were taken from each half-plot.



Twenty-four bunches were thus sampled from each sub-plot in both types of planting for this year.

Sampling technique 1935-40

In the six years 1935 to 1940 the precision observations were taken in the 'season plot' on the farm. A block of 84 ft. × 25 ft. was marked out in this and divided into 12 plots of 7 ft. × 25 ft. Each plot had seven rows of 25 bunches of regular transplanted rice, there being 10 seedlings per bunch. Out of the seven rows in each plot four were chosen at random and a sampling unit of eight bunches from each row was selected as indicated in the technique for regular planting plots in 1934. In all 32 bunches were observed from each plot every time.

Characters observed

Observations were started a fortnight after the transplanting every year and were repeated at weekly intervals, fresh random selection of the sampling units being made on each occasion. For each chosen bunch three characters were observed, namely, the number of culms, the height and the number of leaves. The main plants could not be distinguished from their tillers and so the total number of culms only were noted. The height upto the base of the fully expanded topmost leaf of the plant nearest to the observer in each bunch was recorded.

At the time of the harvest, the bunches on which measurements were taken on the last date were separately cut and threshed and the weights of paddy and straw from each separately recorded. The length of the panicle of the plant whose height was measured was also recorded. The remainder of the plot, after cutting the 32 bunches, was harvested and the yields of paddy and straw so obtained were determined. Table I gives further details regarding the experiment from year to year. The fortnightly rainfall at the station for the period of the experiment is given in Table II.

Results of 1934 observations

As already mentioned, in the year 1934 observations were taken on the 'regular' and 'irregular' sown plots. It will be seen from Table I that the scheme of the experiment was quite uniform during the years 1935 to 1940. In the first year (1934), however, the number of plots, number of samples, etc.

were different and so the data for this year have been discussed separately here. The observations of the six years 1935--1940 have been considered together later.

The layout of the experiment was of the randomized block type with five replications in 1934. Three sampling units of eight bunches each were observed from each of the two sub-plots into which a plot was divided. The allocation of the degrees of freedom for the 480 observations of each character for any one occasion was as follows :

Due to	D. F.
Blocks	4
Treatment*	1
Experimental error	4
Sub-plots	10
Sampling error	40
Within samples	420
Total	479

Of the three characters observed on each occasion, the number of leave. did not show much variation and therefore its variance was not analyseds Tables III(A) and III(B) show the analysed variances for (1) number of culms and (2) height for each day of observation together with the analysis of variance of panicle length, paddy and straw yields at harvest.

The following comparisons have been made and the significant differences in the variances have been indicated in the tables.

(*a*) *Block and treatment variances.* The block and treatment variances have been compared with the experimental error variances. The block variance is not significant showing that the blocks are not any more different from one another than the plots themselves. It is found that, in spite of the small number of degrees of freedom available for estimating the experimental error, only four, the treatment variances are significant in many cases. For the number of culms the treatment variance is highly significant for all the weeks while for height it is significant only for eight weeks. The treatment variance is not significant for panicle length and paddy yield but is significant for straw yield. The significant differences noted above indicate differences in the nature of the crop for the two methods of planting and will be referred to again later in the paper while discussing the mean value of the characters.

(*b*) *Sub-plot variances.* It is desirable, when sampling is resorted to, to sub-divide the units from which samples are taken into one or more parts and take equal number of samples from each sub-unit instead of random samples from the whole, to ensure representative sampling. Sampling will be more efficient, if controlled as above, especially in a population where the unit from which samples are taken exhibits systematic differences within itself. Such differences, if any, will be shown by higher variance between sub-units themselves. In the present experiment it was found that the sub-plot variance is generally less than the 'experimental error' variance except in a few cases. For three weeks in the case of height and for straw yield at harvest, the sub-plot variance is significantly higher. It will be shown later that even this difference is manifest only in the case of irregular planting.

* Methods of planting, i.e. regular and irregular

TABLE I

Statement showing the details of precision observations on rice at Karjat during the years 1934—40

	1934		1935	1936	1937	1938	1939	1940
	Regular	Irregular						
1. Size of the plot (in ft.)	7×50	7×50	7×25	7×25	7×25	7×25	7×25	7×25
2. Number of plots	5	5	12	12	12	12	12	12
3. Date of sowing nursery	11-6-34	11-6-34	8-6-35	4-6-36	14-6-37	5-6-38	9-6-39	8-6-40
4. Date of transplanting	11-7-34	11-7-34	5-7-35	4-7-36	12-7-37	4-7-38	5-7-39	9-7-40
5. Date of first observation	25-7-34	25-7-34	19-7-35	18-7-36	26-7-37	27-7-38	2-8-39	23-7-40
6. Variety of rice	K 226	K 226	K 42	K 42	K 42	K 42	K 42	K 42
7. Spacing of bunches (in inches)	12×12	Irregular	12×12	12×12	12×12	12×12	12×12	12×12
8. No. of seedlings planted per bunch	8	Irregular	10	10	10	10	10	10
9. Sampling method	3 random rows in each sub-plot were chosen and 8 bunches in a dissected manner were observed from each row	3 random locations were made in each sub-plot and with a square frame 8 bunches were observed	4 rows were chosen at random from each plot and 8 bunches in a dissected manner were observed from each row					
10. Date of harvesting	1-11-34	1-11-34	31-10-35	27-10-36	1-11-37	3-11-38	31-10-39	7-11-40
11. Total No. of bunches in each plot	350	...	175	175	175	175	175	175
12. No. of bunches observed each time	48	48	32	32	32	32	32	32
13. Percentage sampled	13·7	Indeterminate	18·3	18·3	18·3	18·3	18·3	18·3

TABLE II

Distribution of fortnightly rainfall during the years 1934—1940 at the Rice Breeding Station, Karjat

Year	May		June		July		August		September		October		November		December		Total
	1—15	16—31	1—15	16—30	1—15	16—31	1—15	16—31	1—15	16—30	1—15	16—31	1—15	16—30	1—15	16—31	
1934	...	...	3·97	29·32	21·03	15·31	23·10	13·30	6·80	3·46	1·75	0·10	2·35	...	...	...	120·49
1935	...	...	1·94	23·85	16·34	34·40	5·86	19·21	11·57	3·14	...	3·65	0·05	...	...	...	120·01
1936	...	...	4·42	32·90	13·42	19·72	16·97	12·73	17·74	2·86	0·01	...	1·69	0·38	...	...	122·84
1937	...	...	0·60	24·87	29·84	41·92	10·33	6·05	14·40	12·76	2·34	0·13	0·06	...	...	...	143·30
1938	...	0·87	20·44	25·97	23·85	32·82	9·92	23·27	5·87	4·83	21·41	...	0·21	...	...	...	169·46
1939	...	...	5·97	7·65	35·54	7·85	4·25	39·72	7·60	1·33	0·61	1·21	0·24	...	...	...	111·97
1940	...	...	2·69	26·12	17·16	44·27	21·26	21·71	4·72	19·28	1·67	5·13	...	0·29	...	...	164·30

TABLE III (A)

Analysis of variance of number of culms for each week and harvest characters for 1934

Factor	D. F.	Number of culms per bunch														Harvest character		
		Number of the week														Panicle length in cm.	Straw yield in gm.	Paddy yield in gm.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14			
Blocks . .	4	44·0	46·7	77·7	45·9	52·4	18·1	12·9	37·7	9·4	19·9	10·7	10·9	11·5	11·6	15·9	19·7	131·6
Treatment .	1	4183·1‡	3167·3‡	3996·3‡	3713·0‡	1884·2‡	2336·4‡	1533·7‡	3582·1‡	2079·2‡	1555·2‡	1530·1‡	1569·6‡	2622·7‡	1687·5‡	468·2	492·1‡	15·7
Experimental error . .	4	38·8	53·5	16·6	33·6	35·2	48·5	13·0	36·3	38·9	11·5	9·5	27·4	20·2	30·3	122·2	19·6	54·4
Sub-plots .	10	13·9	27·9	31·5	31·1	14·8	26·3	14·0	12·0	10·3	17·1	9·0	18·0	19·5	19·3	2·8	151·5†	134·5
Sampling .	40	16·3‡	11·9‡	13·9‡	9·7	17·8‡	6·8	14·4‡	8·0†	12·0	8·7	17·7‡	10·9‡	18·0‡	12·6‡	4·4†	26·1	58·6†
Within samples	420	6·8	5·9	7·8	7·7	6·6	6·5	6·8	5·5	9·1	7·0	6·3	6·2	7·0	6·1	2·8	26·7	33·6

TABLE III (B)

Analysis of variance of height (in cms.) observations for each week in 1934

Blocks . .	4	41·3	12·0	7·4	23·5	46·0	12·9	55·3	45·4	198·8	67·2	483·7	703·4	549·1	776·8‡	...	...	...
Treatment .	1	56·7	129·2†	401·5‡	95·4	262·6†	48·1†	0·3	298·4‡	6·8	221·4	3146·8	578·6	21362·4	2325·4‡	...	...	...
Experimental error . .	4	54·0	13·6	12·8	19·0	27·6	4·4	31·4	14·0	33·7	32·7	508·6	632·6	175·1	19·3	...	...	...
Sub-plots .	10	11·6	11·1	3·8	9·7	3·1	46·7†	28·2	134·8†	55·7	127·4	328·3	258·9	124·5	478·3‡	...	...	...
Sampling .	40	9·9‡	4·6	5·1	4·4	5·1	10·1†	10·8	5·7	28·7†	55·3‡	148·5‡	352·7‡	119·1‡	119·6‡	...	...	...
Within samples	420	5·1	4·0	3·7	5·5	6·9	6·8	11·2	14·6	17·9	32·5	59·7	60·1	62·0	50·4	...	...	...

† Significant at 5 per cent level ‡ Significant at 1 per cent level

(c) *Sampling variance.* The sampling variance is seen to be generally higher than the 'within samples' variance and significantly so in many cases. This indicates the existence of a positive correlation between the ultimate units, i.e. the bunches in the same sample.

The comparisons made above are based upon the variances estimated from the samples taken from both the methods of planting. It is, however, recognized that differences in sampling errors may arise due to variation in the structure of the sampling unit [Kalamkar, 1932] and in the present case due to differences in the methods of planting. In view of this fact analyses of variance have been carried out separately for the two methods of sampling for all the above observations and are shown in Tables IV (A) and IV (B).

A comparison of the sub-plot variance with plot variance in these tables indicates that generally they are not significantly different though for a few cases in 'irregular planting' the differences are significant. It thus appears that there is no advantage in dividing the plots of the size used in the experiment into smaller units for the purposes of sampling especially in dealing with the crop planted regularly.

The 'sampling' and 'within samples' variances, in Tables IV (A) and IV (B) when compared indicate that the positive correlation between the bunches within the same sample is not peculiar to one method of planting alone, for significant differences occur for both methods. While the presence of this correlation in the linear sampling unit of the regular planting may lead one to suspect that the adjacent bunches chosen therein might have been the cause, the presence of a similar correlation in the irregular crop from which the bunches have been chosen along the sides of a square yard indicates that the correlation may exist not only among bunches quite near each other but also among bunches in the same locality. Considering, however, the normal spacing in an irregular crop it is quite possible also that a few of the bunches in each sample from the irregular crop were located adjacently and so it is not possible to say whether this correlation is a feature of adjacent bunches alone or amongst bunches in the same locality without further studies. It appears, however, that both the sampling structures, i.e. the linear one for the regular crop and the square-yard one for the irregular crop require modification in the light of the above results.

Table V shows the experimental and sampling errors derived from Tables IV(A) and IV(B) as percentages of mean values of the characters concerned for each week's observations and harvest characters. Comparing these errors for the two methods of planting it is seen that the method of planting does not show any consistent difference on the experimental or sampling errors. While in certain cases the errors are higher for the irregular planting, there are instances where the reverse is also true though on an average the errors for the irregular planting are slightly higher than those for the regular planting.

The mean values of number of culms per bunch, the height and the number of leaves for each week of observation together with the mean values of the harvest characters are shown in Table VI. The experimental and sampling errors for the means are also shown for each week and for the harvest characters except for the number of leaves. Fig. 1 shows graphically the mean heights and the mean values of the number of culms.

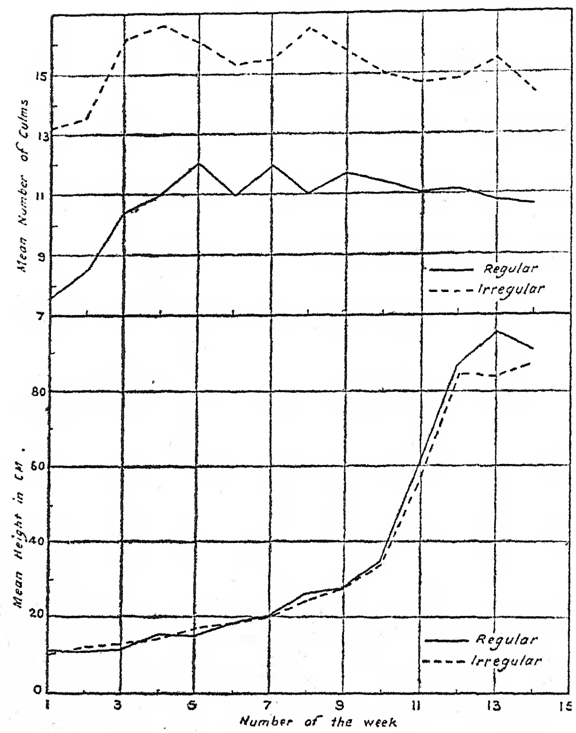


FIG. 1.

The number of culms per bunch for the cultivator's method has been significantly higher than in the case of regular planting. In the irregular planting there are on an average 4 to 5 culms per bunch more than in the regular planting. At harvest the numbers of culms per bunch are 10·7 and 14·4 for regular and irregular planting respectively.

The heights of the plants in the two methods of planting do not show much difference during the early stages of the crop but during subsequent stages however the plants in the regular method show greater height.

It is curious to note that the average height of the plants taken at the time of harvest in the regular planting shows a significantly lower value than the average height observed a fortnight before, due to defective sampling. In general, however, no such significant discrepancies were noticed in respect of the attributes measured.

The final height of the plant and the panicle length for the irregular method show significantly lower values, while the number of culms and the yield of straw per bunch show higher values than for the regular planting. There was, however, no significant difference in the yield of paddy for the two methods; the shorter panicle length probably acted as a set off against the greater number of culms per bunch. However, the greater number of culms per bunch has reflected in the higher straw yield for the cultivator's method.

TABLE IV(A)

Separate analysis of variance for 'regular' and 'irregular' crops for 1934 : Number of culms per bunch for each week and harvest characters

Factor	D. F.	Number of culms per bunch: No. of the week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Harvest characters: Panicle length in cm.	Straw yield in gm.	Paddy yield in gm.
(i) Regular																		
Plots	4	4·9	5·2	32·0	14·6	57·5	25·4	3·2	24·2	14·3	14·9	2·4	29·1	10·9	5·4	3·3	17·1	162·6
Sub-plots	5	9·0	5·7	20·4	2·6	2·6	13·1	8·9	5·9	2·4	3·2	9·3	14·5	1·4	13·4	4·3	101·0	93·9
Sampling	20	5·2‡	3·2	11·7‡	7·7	5·0	4·4	7·2	5·0	8·4‡	4·6	9·5‡	4·2	8·0‡	5·5†	4·0‡	32·3	48·3
Within samples	210	1·8	2·3	4·6	5·9	4·7	4·4	5·3	3·7	4·2	3·8	3·2	3·8	3·1	3·1	2·1	21·3	31·0
(ii) Irregular																		
Plots	4	77·9	95·0	62·3	65·0	30·2	41·2	22·7	49·8	34·0	16·5	17·8	9·3	20·7	36·5	17·8	22·2	23·4
Sub-plots	5	18·9	50·0	42·6	59·5	27·0	39·5	19·2	18·0	18·1	31·0	8·7	21·4	37·7	25·2	1·4	202·1†	175·2†
Sampling	20	27·5‡	20·7‡	16·7	11·7	30·6‡	9·2	21·7‡	11·0	15·6	12·9	25·9‡	17·4‡	27·9‡	19·7‡	4·9	19·9	68·9†
Within samples	210	11·7	9·5	11·1	9·5	8·6	8·6	8·4	7·5	13·9	10·2	9·4	8·5	10·9	9·2	3·5	32·1	41·9

† Significant at 5 per cent level ‡ Significant at 1 per cent level

TABLE IV(B)

Separate analysis of variance for 'regular' and 'irregular' crops for 1934 : Height in cm. for each week of observation

Factor	D. F.	Number of culms per bunch													
		No. of the week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
(i) Regular															
Plot	4	12·3	1·7	10·1	27·9	41·4	7·4	48·0	45·9	145·8	89·8	249·7	224·5	644·6	367·4
Sub-plots . . .	5	10·0	7·6	3·7	11·1	4·1	33·4	24·7	31·4	64·7	74·5	335·8	236·2	69·8	148·8
Sampling . . .	20	12·9‡	3·0	6·2†	4·8	3·4	13·1‡	10·9	19·0	22·4	52·2‡	98·8‡	86·0	144·8‡	57·2
Within samples . .	210	6·4	4·1	3·9	5·7	6·7	6·6	13·0	12·8	16·9	26·4	49·0	82·7	51·8	41·9
(ii) Irregular															
Plot	4	83·0	23·9	10·2	14·6	32·2	9·9	38·8	13·4	86·4	10·0	742·5	1111·5	79·6	431·5
Sub-plots . . .	5	13·3	14·6	3·9	8·3	2·2	60·1†	31·8	38·1	46·6	180·4‡	320·8	281·7	179·2	309·7
Sampling . . .	20	6·9†	6·2	4·0	4·1	6·9	7·2	10·7	42·4‡	34·7†	58·5	198·2‡	619·4‡	93·5	181·9‡
Within samples . .	210	3·9	3·9	3·6	5·2	7·1	6·9	9·5	16·6	18·2	38·6	70·5	37·4	72·2	59·0

† Significant at 5 per cent level

‡ Significant at 1 per cent level

TABLE V

Percentage experimental and sampling errors for 'regular' and 'irregular' crops for each week and harvest characters

Week No.	Culms per bunch				Height in cm.			
	Percentage error per bunch separate for the two methods of planting				Percentage error per bunch separate for the two methods of planting			
	Regular		Irregular		Regular		Irregular	
	Experimental error	Sampling error	Experimental error	Sampling error	Experimental error	Sampling error	Experimental error	Sampling error
1	30·3	31·0	..	..	31·3	32·0	86·3	24·9
2	27·1	21·3	77·4	33·4	11·9	15·6	40·4	20·6
3	54·5	32·9	48·8	25·2	26·8	21·1	23·3	14·5
4	34·4	24·9	48·4	20·6	34·0	14·1	26·0	13·8
5	62·5	18·4	34·1	34·3	41·1	11·7	33·1	15·3
6	46·3	19·3	41·9	19·8	14·3	19·0	17·1	14·5
7	15·1	22·6	30·8	30·1	33·6	16·0	30·3	15·9
8	44·3	20·1	42·5	20·0	26·1	18·2	15·0	26·5
9	32·3	24·9	36·8	24·9	42·9	16·8	33·3	21·1
10	33·9	18·8	27·1	23·9	26·6	20·3	9·2	22·3
11	14·0	27·8	28·7	34·6	25·8	16·3	48·6	25·1
12	48·2	18·2	20·6	28·2	17·4	10·7	39·7	29·6
13	30·6	26·2	29·3	34·1	26·5	12·7	10·7	11·6
14	21·8	21·9	41·9	30·8	21·0	8·3	23·9	15·5
Harvest characters								
Panicle length in cm. .					8·6	9·4	21·9	11·5
Straw yield in gm. .					57·8	32·8	22·5	38·5
Paddy yield in gm. .					18·4	25·3	19·2	18·2

TABLE VI

Mean values with their experimental and sampling errors for number of culms, etc. for each week and harvest characters 1934

Week No.	Number of culms				Height in cm.				Mean number of leaves	
	Mean		Experimental error for the mean	Sampling error for the mean	Mean		Experimental error for the mean	Sampling error for the mean	Regular	Irregular
	Regular	Irregular			Regular	Irregular				
1	7 ·3	13 ·2	·428	·261	11 ·2	10 ·5	·415	·020	3 ·5	2 ·9
2	8 ·5	13 ·6	·441	·223	11 ·1	12 ·1	·225	·138	4 ·0	3 ·6
3	10 ·4	16 ·2	·569	·241	11 ·8	13 ·7	·174	·145	4 ·0	3 ·8
4	11 ·1	16 ·7	·438	·201	15 ·6	14 ·7	·313	·136	4 ·1	4 ·2
5	12 ·1	16 ·1	·467	·272	15 ·6	17 ·1	·438	·146	4 ·6	4 ·1
6	10 ·9	15 ·3	·275	·168	19 ·0	18 ·4	·232	·205	4 ·1	4 ·3
7	11 ·9	15 ·5	·232	·245	20 ·6	20 ·6	·480	·212	4 ·9	4 ·2
8	11 ·1	16 ·6	·396	·182	26 ·1	24 ·5	·435	·015	4 ·3	4 ·2
9	11 ·7	15 ·8	·198	·224	28 ·1	27 ·9	·910	·346	4 ·6	4 ·6
10	11 ·4	15 ·0	·288	·191	35 ·7	34 ·3	·529	·480	4 ·8	4 ·8
11	11 ·1	14 ·7	·211	·272	61 ·1	56 ·0	1 ·420	·787	5 ·1	5 ·2
12	11 ·2	14 ·8	·214	·213	86 ·2	84 ·0	1 ·712	1 ·212	4 ·1	3 ·4
13	10 ·8	15 ·5	·218	·274	95 ·8	83 ·6	1 ·513	·705	3 ·1	2 ·7
14	10 ·7	14 ·4	·220	·229	91 ·4	87 ·0	1 ·799	·706	3 ·7	3 ·6

Harvest characters

	Regular	Irregular	Experimental error for the mean	Sampling error for the mean
Panicle length in cm. . . .	21 ·20	19 ·23	·258	·135
Straw yield in gm. . . .	22 ·48	24 ·50	·091	·104
Paddy yield in gm. . . .	21 ·20	21 ·56	·219	·179

Results of observations 1935—1940

The results of 1934 observations have been discussed in some detail above as observations were taken in 'regular' and 'irregular' sown plots. For the years 1935—1940 the observations have been carried out in the case of one method of planting only (i.e. regular) in 12 plots. Further details of the nature of the experiment have already been shown in Table I. The characters observed were the same as in 1934, namely, the number of culms in each bunch, the height of bunch and the number of leaves per bunch for each time of observation together with the panicle length and the yields of straw and paddy at harvest. In these years four sampling units were taken from each plot without subdivision. The analysis of variance for the 384 observations taken for each character at a time will thus have the following allocation of degrees of freedom :

Due to	D. F.	Variance
Plots	11	A
Sampling error	36	B
Within samples	336	C
Total	383	

The analysis of variance has been carried out for all the characters observed except for leaves where no appreciable variability was noticed. Tables VII(A) and VII(B) give in a tabular form the mean values of the number of culms per bunch and the mean height in cm. for the various weekly observations together with their percentage sampling errors per bunch. At the bottom of Table VII(B) are also given the mean values of other characters observed at harvest, namely, the panicle length, the paddy and straw yields per bunch for the respective years. The mean number of leaves are also shown in Table VII(C). The mean values of number of culms and the height for various years are shown graphically in Fig. 2 which brings out the differential response of the characters to seasons. It may be interesting to note that the year 1937 seems to have been the most favourable season for the crop. In this year, the number of culms, the height at harvest and the yield of paddy were the highest among the 6 years under consideration.

Growth features of the crop. The crop gets ready for harvest within 15 to 16 weeks after its transplantation. Observations on crop growth were started after a fortnight of its transplantation. From a study of Fig. 2 it will be observed that, in general, the number of culms increases and attains a maximum by the sixth or seventh week after transplantation, remains more or less constant for about a fortnight and then decreases due to the fact that some of the late formed tillers do not survive. This decrease is to be noticed for about three weeks by which time the crop is 13 weeks old from transplantation and thereafter the average number of culms remains constant till the harvest. It will be seen from the figure that the maximum for the number of culms reached was more for the seasons 1935 and 1937 but the survival was greatest for 1937 only. In other years the average number of culms at harvest was more or less the same.

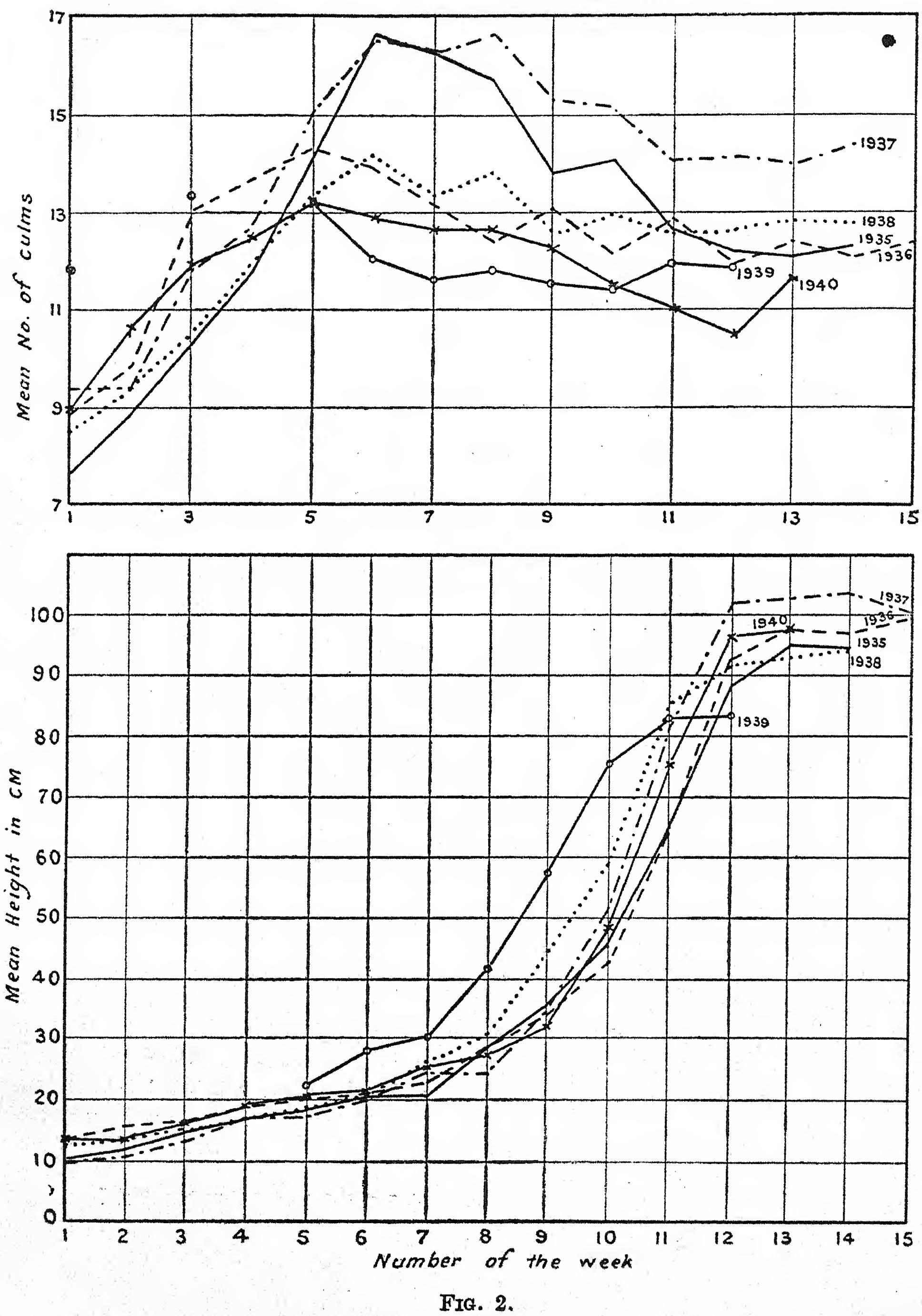

Mean No. of culms
17
15
13
11
9
7
1
3
5
7
9
11
13
15
1937
1938
1935
1936
1939
1940
Mean Height in CM
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1937
1940
1936
1935
1938
1939
Number of the week

FIG. 2.

TABLE VII(A)

Mean values of number of culms per bunch for each week together with the percentage sampling errors, 1935—40

Week No.	1935		1936		1937		1938		1939		1940	
	Mean	Sampling error per cent per bunch	Mean	Sampling error per cent per bunch	Mean	Sampling error per cent per bunch	Mean	Sampling error per cent per bunch	Mean	Sampling error per cent per bunch	Mean	Sampling error per cent per bunch
	Starting date of observations											
	19-7-35		18-7-36		26-7-37		27-7-38		2-8-39		23-7-40	
1	7·7	17	8·8	34	9·3	15	8·5	..	11·8	19	9·0	20
2	8·8	23	9·8	21	9·3	15	9·4	..	..	..	10·7	22
3	10·3	23	13·0	21	11·8	24	10·6	28	13·4	15	12·0	18
4	11·8	17	11·8	18	12·7	22	12·0	25	..	..	12·5	18
5	14·2	43	14·3	21	15·0	21	13·4	19	13·4	21	13·2	19
6	16·7	19	13·9	24	16·6	17	14·2	16	12·1	13	12·9	14
7	16·3	15	13·2	19	16·3	16	13·4	20	11·7	17	12·7	19
8	15·7	14	12·4	18	16·6	19	13·9	20	11·8	19	12·7	17
9	13·8	15	13·1	16	15·3	16	12·7	19	11·5	15	12·3	15
10	14·1	14	12·1	18	15·2	16	13·0	19	11·4	16	11·6	16
11	12·7	16	12·8	18	14·1	19	12·6	19	11·9	16	11·1	16
12	12·2	13	11·9	21	14·2	15	12·7	16	11·8	13	10·6	18
13	12·1	18	12·4	14	14·2	15	12·8	21	..	..	11·7	14
14	12·3	14	12·1	14	14·0	21	12·8	18	..	..	..	..
15	..	..	12·3	14	14·4	17	..	..	..	..	..	..
16	..	..	..	..	..	..	..	..	..	..	11·1	18

TABLE VII (B)

Mean values of height for each week and of harvest characters together with their percentage sampling errors, 1935—40

Week No.	1935		1936		1937		1938		1939		1940	
	Mean (cm.)	Sampling error per cent per bunch	Mean (cm.)	Sampling error per cent per bunch	Mean (cm.)	Sampling error per cent per bunch	Mean (cm.)	Sampling error per cent per bunch	Mean (cm.)	Sampling error per cent per bunch	Mean (cm.)	Sampling error per cent per bunch
Starting date of observations	19-7-35		18-7-36		26-7-37		27-7-38		2-8-39		23-7-40	
1	10·1	20	13·6	19	9·6	22	12·9	..	14·1	17	11·1	15
2	12·0	17	15·4	16	11·7	20	13·2	..	..	..	13·3	19
3	15·5	13	16·2	11	13·5	18	13·8	17	17·8	13	16·1	17
4	16·5	10	18·6	13	17·0	11	17·1	11	..	..	19·1	13
5	18·4	18	19·8	15	17·9	10	19·6	13	22·3	10	20·4	9
6	20·7	9	21·1	12	20·4	10	21·4	18	28·0	11	21·8	12
7	21·0	8	23·3	17	25·1	12	26·7	13	29·9	10	24·9	15
8	29·2	13	28·2	12	24·4	20	31·5	15	41·8	10	27·9	10
9	35·7	12	33·7	16	34·2	14	44·3	16	57·9	14	32·6	19
10	45·8	12	42·5	11	51·1	15	59·7	15	75·4	8	48·3	12
11	65·5	9	62·9	12	80·1	10	85·4	8	83·1	8	75·4	9
12	88·6	8	92·6	9	101·5	8	91·8	6	83·2	8	96·1	6
13	95·2	7	97·8	8	102·7	9	92·2	8	..	..	97·7	6
14	94·7	7	97·1	9	103·6	8	93·8	7	..	..	..	..
15	..	..	98·8	9	100·6	10	..	..	..	..	..	..
16	..	..	..	..	..	..	..	..	..	..	100·0	8
Panicle length at harvest in cm.	..	..	23·9	11	21·8	11	22·5	8	21·0	9	23·3	7
Mean yield of straw in gm. per bunch	38·1	18	30·9	22	33·0	24	27·8	23	25·5	16	25·5	22
Mean yield of paddy in gm. per bunch	23·9	15	26·7	21	31·5	22	26·8	25	24·5	18	22·7	30

TABLE VII(C)

Mean number of leaves per plant for each week's observation for the years 1935—40

Week No.	1935	1936	1937	1938	1939	1940
1 .	3·4	3·3	3·1	4·7	4·2	3·0
2 .	4·1	3·9	3·4	4·6	..	4·0
3 .	4·1	4·0	3·7	4·6	4·5	4·8
4 .	4·3	4·4	4·0	4·6	..	5·0
5 .	4·6	4·4	4·3	4·4	4·9	5·1
6 .	4·4	4·7	4·4	4·6	4·5	5·0
7 .	4·6	4·7	4·6	4·8	4·8	5·0
8 .	5·1	4·9	4·4	5·0	5·0	5·0
9 .	5·3	5·0	5·2	4·7	5·1	5·0
10 .	5·3	5·1	5·1	3·6	4·1	5·1
11 .	5·1	4·6	4·7	3·0	3·7	5·0
12 .	4·3	5·1	3·4	1·9	2·8	4·0
13 .	3·4	4·2	..	..	..	3·0
14 .	2·5	2·8	..	..	..	..
15 .	..	1·6	..	..	..	..
16 .	..	..	..	..	..	..

The period of quickest growth of the crop as indicated by its average height taken up to the base of the topmost fully expanded leaf appears to be during the 8th to 13th week from transplantation. The height attains its maximum by the 13th week and remains constant thereafter. The average height attained was greatest for the year 1937.

Suitability of the sampling structure. While discussing the results of 1934 observations, it was found that the 'sampling variance' was generally higher than the 'within samples' variance, indicating a positive correlation between the bunches in the same sample. For the years 1935—40 Tables VIII(A) and VIII(B) give the values of the above two variances for a similar comparison.

It will be seen that the variance due to 'within samples' is generally smaller than that due to 'sampling' in these years also, but only in a few of the cases does it reach the five per cent level of significance. The consistency of

this difference from year to year shows that structure of the sampling unit requires slight revision.

To see whether the positive correlation between the bunches in the same sample was mainly contributed by the adjacent pairs of bunches only or whether bunches in the same locality were also so correlated, the variances within samples for a few occasions were analysed into two parts, namely (1) the variance between pairs within the same sample and (2) the variance within pairs, i.e. between bunches in the same pair. In 1934 only the observations taken in the regularly sown crop were used for this analysis. Tables IX (A) and IX(B) give these variances. The differences in the 'between pair' variance and 'within pair' variance have been tested by the z-test and those differences which are significant are indicated in the table.

It will be found that in all the cases chosen for this analysis, the 'within samples' variance was significantly lower than the 'sampling variance', thereby showing the positive correlation between the bunches. Now it is found from Table IX(A) and IX(B) that only in some of the cases the 'within pair,' variance is lower than the 'between pair' variance. In other cases these two variances are equal. It appears therefore that the positive correlation within samples is not only contributed by the adjacent bunches in samples but between other bunches or pairs of bunches in the same locality.

The above results point to one conclusion, namely that the structure of the linear sampling unit requires a change if the sample is to be more representative of the crop. It may be mentioned here that for the wheat crop a sampling structure in which the units are taken on parallel rows has been found to be more efficient than a linear structure as in the present experiment [Kalamkar, 1932]. A similar structure, taking care to see that adjacent bunches are not taken in a sampling unit, may prove suitable for this crop also.

Efficiency of sampling. The sampling and experimental errors together with the 'non-sampling experimental error' (an estimate of what the experimental error would have been if the whole plot had been sampled) and the percentage information obtained by sampling as calculated from the formulae evolved by Yates and Zacopanay [1935] are shown in Tables X(A) and X (B). The percentage errors are given per plot (based on 32 bunches). The estimates of the experimental errors for the various observations are fairly within the usual limits, most of them lying within 6 per cent. As is to be expected the experimental errors are in general greater than the sampling errors. The percentage information obtained in the case of culms and heights varies from 70 to 90 per cent in most cases. It will be observed from the tables that both in the case of culms and height the percentage sampling errors in general decreased as the crop advanced in growth.

Comparison of the estimated and the actual yields. The yields of paddy and straw for the whole plot, as estimated from the sampling yields, are given in Table XI together with the corresponding actual yields obtained by entire harvest of the crop. Taking the total actual and estimated yields over all the plots in each year the differences have been expressed as a percentage of the actual yields below Table XI. Except in 1936, when there was an over estimation of 8·82 per cent the percentage differences are all small, showing that the sampling has been on the whole satisfactory. The plot errors as calculated from the actual and estimated yields are also found to agree fairly.

CONTENTS

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ORIGINAL ARTICLES

GROWTH AND YIELD STUDIES ON IRRIGATED PADDY IN UPPER BURMA

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(With six text-figures)

Any attempt to analyse the factors which contribute to the yield of a cereal crop must commence with a detailed study of the development of the plant, especially the formation and survival of tillers. The work of Engledow *et al.* on wheat and barley at Cambridge has laid the foundation of this type of study. Summers [1921] published results of studies on the tillering of paddy in Ceylon, in which he compared the root development and tillering of broadcast and transplanted paddy, recording that in transplanted paddy the number of panicles produced is greater, tillering more regular and root development greater. Joshi and Gadkari [1923] studied the growth of paddy as affected by environment in Bombay and Bhide and Bhalerao [1927] related growth to height of plant. Correlation studies between characters in rice have been reported by Jacobson [1916] and Vibar [1921] in the Philippines and by Rao [1937] in Madras. Ramiah and Narasimham [1936] studied the growth and tillering of paddy in Madras. We are in general agreement with the results reported by Grant [1935] and by Grant and Thein Aung [1941] for Lower Burma paddy. We have attempted to trace the course of growth and tillering at different spacings, to ascertain the fate of the tillers of different orders and to discover the contribution of each towards the final yield. That it is not necessarily the late-formed tillers which succumb prematurely but that the primary stem may suffer early death is clearly brought out. The relationship between height of seedling at transplanting and subsequent growth has been studied.

Conditions of the experiments

The present experiments were carried out at Mandalay in Upper Burma with irrigated paddy. The annual rainfall is about 33 in. and the soil a heavy black carbonate solonschak clay of pH 8. Under normal conditions nurseries are sown about the middle of June and the paddy is transplanted 35 to 40 days later in groups of four to seven seedlings about 10 in. apart. This method of planting is referred to as *htonsan*. Since *htonsan* planting prevents a study of the tillering of individual plants most of these experiments have been done with single seedlings at fixed spacings, though some have been done with *htonsan* planting. Because much of the counting of tillers was done by fieldmen it was considered safer not to enter the numbers of tillers (i.e. number of culms less one) in the records which consequently show the total number of stems. To avoid re-writing voluminous data analysis has in most cases been done on total culm numbers and not on tiller numbers.

Newly transplanted paddy, especially when single seedlings are planted, is much damaged by the land crab *Potamon dayanum* Wood-Mason. Wherever plants are cut by crabs the neighbouring plants benefit by the extra space and respond by more tillering, necessitating the rejection of all plants adjacent to gaps from most of the tillering records. In the 1932 experiments the mean number of tillers for all varieties and treatments was 11·15 for plants adjacent to gaps against 10·32 for those not so placed, a difference of 0·83 ($P > 0{\cdot}01$). Wherever necessary plants so benefited have been disregarded.

Crude tillering curves

An experiment was laid down in 1932 using four varieties, the planting being with single seedlings at 1 ft. × 1 ft. spacing from the same nursery raised under closely similar conditions. The outside and end rows were neglected as well as all plants adjacent to gaps caused by crabs. Cultivation and irrigation were in accordance with the normal local practice. Table I gives the mean stem numbers of approximately 500 plants for each variety at each count.

Table I

Mean stem numbers of four varieties of paddy, 1932

Date of count	Days from transplanting	Ngakyi C406	Ngasein C401	Taung-deikpan B401	Paung-malaung C410
11-8-32	0	1·00	1·00	1·00	1·00
2-9-32	22	4·58	3·55	4·69	3·82
12-9-32	32	12·84	7·94	11·54	11·75
22-9-32	42	18·44	13·63	14·29	15·99
3-10-32	53	19·63	15·02	14·75	16·44
13-10-32	63	19·98	15·46	15·22	16·38
23-10-32	73	19·42	15·06	14·76	15·56
2-11-32	82	16·76	13·15	12·46	13·96
12-11-32	92	13·69	10·13	11·03	Ripe
22-11-32	102	13·28	9·87	Ripe	..

In Fig. 1 the curves of tiller numbers are shown. There is a period of recovery from transplanting followed by a rapid rise in tiller numbers until a

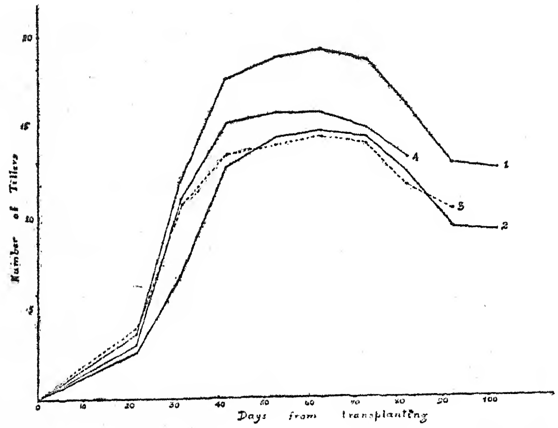

FIG. 1. Tiller numbers of 1. Ngakyi, 2. Ngasein, 3. Taungdeikpan, and 4. Paungmalaung

maximum is reached in about 63 days from transplanting. Thereafter there is a decline due to deaths of tillers until the plants ripen. Mitra and Ganguli [1932] found that the maximum number of tillers was formed about the 7th or 8th week after transplanting. In the present experiments the period of maximum tillering appears to be about the 9th week. The losses of tillers range from 27·5 to 36·1 per cent for the long-lived varieties Ngakyi, Ngasein and Taungdeikpan, while the early Paungmalaung suffered only 15·1 per cent loss. These losses are of a similar order to those recorded by Grant [1941] and Ramiah [1936]. Doughty and Engledow [1928] have formulated the idea of a critical period, a date after which any tillers formed fail to mature. From the above data it would appear that the critical periods for these four varieties would be approximately :

	Days after trans-planting	Date
Ngakyi (C406)	33	13-9-32
Ngasein (C401)	35	15-9-32
Taungdeikpan (B401)	31	11-9-32
Paungmalaung (C410)	37	17-9-32

Later experiments have shown that it is incorrect to assume that all tillers formed after these dates are doomed to failure. The critical dates as determined from the crude tillering curve average about 33 days from transplanting, and as there is a period of about 10 to 15 days after transplanting while the plants are recovering from the damage of uprooting there would remain only about three weeks for tiller formation. Actually the case is more complicated and if there is a critical period it does not occur till much later.

In 1933, experiments were done in which a number of plants were selected at random from plots planted at two spacings and tiller counts were made on these selected plants, each tiller being marked with a small label at the time it was first recorded, thus enabling a complete history of each stem to be made from the recording date onwards. Twelve plants were selected at random from a population of 500 of each of two varieties spaced 1 ft. × 1 ft. and 2 ft. × 2 ft. (Appendix Tables I to IV).

The figures are somewhat irregular due to the small numbers of plants counted but the effect of spacing on the numbers of tillers formed is very marked, and also the difference between the varieties.

Fig. 2 shows the actual numbers of tillers formed and died on each recording date. In Taungdeikpan tillering begins about a fortnight after transplanting. At the 1 ft. × 1 ft. spacing the maximum rate is quickly reached after which there is a fairly steady decline until by the beginning of November only occasional tillers are formed. At the 2 ft. × 2 ft. spacing the tillering rate is very irregular, periods of active tiller formation seeming to alternate with periods of lessened activity, but there is a similar general decline to that shown at the closer spacing. Tiller deaths commence about 4 October at the closer spacing and are first recorded 10 days later at the wider spacing. At the closer spacing there are two modes for the death rate at 19 October and 10 November but at the wider spacing there is only one peak at 2 November. It seems probable, from a consideration of the other curves, that the mode at 10 November was fortuitous.

Ngasein follows the same general course as Taungdeikpan, the rate of tillering at the 1 ft. × 1ft. spacing steadily declining after the initial high rate is reached while the rate at the wider spacing shows great irregularity but a general decline. The death rates correspond closely with those of Taungdeikpan showing modes on 19 and 26 November. In general the time of greatest tiller mortality falls between the middle and third week of November.

It is noteworthy that the irregularities shown by both varieties at the wider spacing correspond closely. If the rainfall in summed ten-day totals is plotted, it is seen (Fig. 3) that there are three modes corresponding to the tillering modes of the 2 ft. × 2 ft. spacing (where presumably space was not a limiting factor) but displaced to the left by about 15 days. Such a lag in the effect of rain would be expected. It may at first seem anomalous that rain should have a large influence on an abundantly irrigated paddy crop but there is not only the actual precipitation involved but the beneficial effects of cooling and the lowering of the transpiration rate to be considered. The

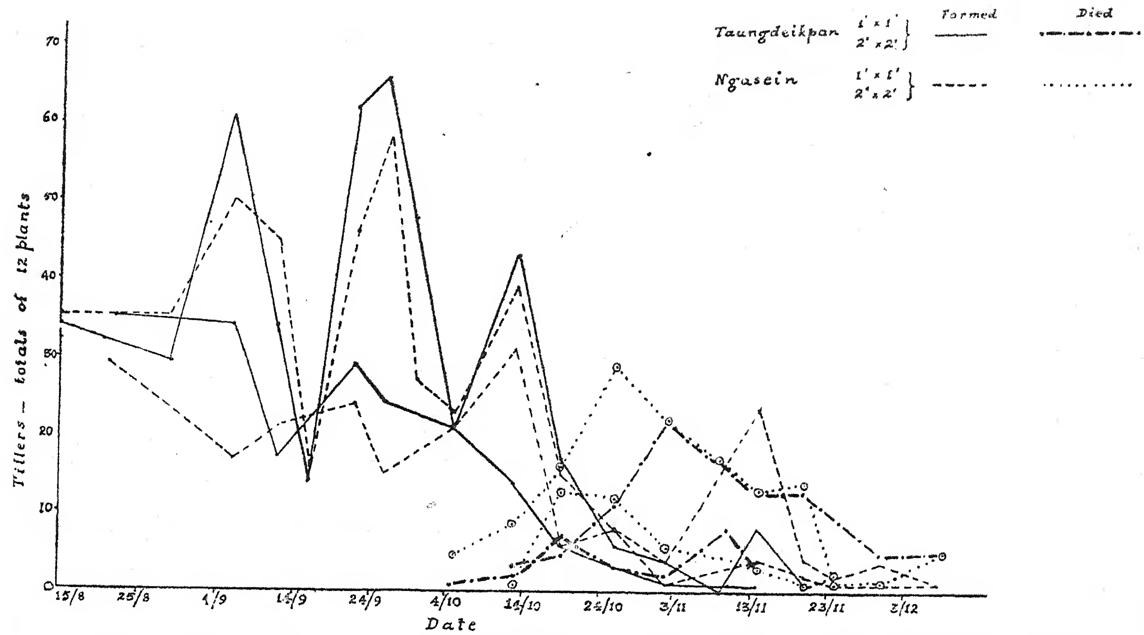

FIG. 2. Actual number of tillers formed and died on each recording date for 1. Taungdeikpan, and 2. Ngasein, in 1933

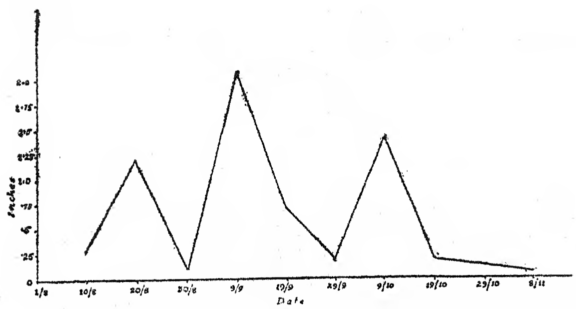

FIG. 3. Rainfall at Mandalay in ten-day periods in 1933

cultivator's belief in the advantages of rain over irrigation water is undoubtedly well founded.

In 1934 this experiment was repeated with group planting (*htonsan*) added and records of the dates of formation of tillers were begun earlier (Appendix, Tables V to X). Although differing in details the general course of tillering is similar to that in 1933. The closer the spacing the earlier and more sharply does the rate of tiller formation decline while concomitantly deaths begin earlier

In this season two modes for rate of tillering are shown by the 2 ft. × 2 ft. spacing against three modes in 1933. Examination of the rainfall shows three modes but the last heavy rainfall period ended on 19 October and was probably too late to stimulate tillering. This was 10 days later than the third rainfall mode in 1933.

Although the periods of rainfall and tillering activity seem to show some correspondence after allowing for about a fortnight's lag, the agreement is not exact. Rainfall alone is not a safe guide to growing conditions since cloudy cool days without any, or with very little, precipitation may be equally effective while, as the season advances and the plant's ability to respond decreases, the influence of rainfall and other climatic factors will decline.

1933			1934		
Tillering modes	Rainfall modes (end dates)	Difference days	Tillering modes	Rainfall modes (end dates)	Difference days
6 Sept.	20 Aug.	17	3 Sept.	20 Aug.	14
26 Sept.	9 Sept.	13	17 Sept.	19 Sept.	2
12 Oct.	9 Oct.	3	..	19 Oct.	..

ORDER OF TILLERING AND TILLER DEATHS

The detailed records of individual tillers made in 1934 and 1935 enable the fate of each tiller to be traced (Tables II and III). In the case of *htonsan* planting the whole group of seedlings has been treated as one unit, and the individuals not separately recorded. While there is a good deal of irregularity (probably due to small numbers) the figures show that there are no distinct periods of tiller formation and tiller death, but that loss of tillers commences early before the maximum number is attained and that formation and loss of tillers proceed concurrently. Ther tend to be a

progressive increase in death rate which with crowding soon reaches 100 per cent but at wide spacings even the latest-formed tillers have some chance of maturing. It is noteworthy that quite a large proportion of the main stems died prematurely even at the widest spacing. Perhaps being situated in the centre of a number of rapidly developing tillers produced too severe competition for nutrients or there may even have been a drain of nutrients from the main stem to the laterals.

Table II

1934

Order of tillering and percentage of deaths

Order of tillering	Date first recorded	Taungdeikpan, per cent death			Ngasein, per cent death		
		Htonsan	1 ft. × 1 ft.	2 ft. × 2 ft.	*Htonsan*	1 ft. × 1 ft.	2 ft. × 2 ft.
1	Main stem	20·00	8·33	16·66	12·50	0	25
2	13-8-34	16·66	3·93	7·14	5·55	7·14	0
3	20-8-34	18·75	11·84	13·50	19·05	14·28	8
4	27-8-34	76·92	19·60	16·66	69·76	18·18	21·90
5	3-9-34	41·66	27·44	19·17	87·10	27·78	21·13
6	10-9-34	55·55	33·33	20·37	90·90	58·33	17·65
7	17-9-34	50·00	57·14	16·66	100·00	57·69	9·46
8	24-9-34	100·00	57·14	23·59	100·00	91·66	29·17
9	1-10-34	..	50·00	24·61	..	100·00	37·78
10	8-10-34	..	..	26·31	..	..	61·36
11	15-10-34	..	..	..	..	..	42·50
12	22-10-34	..	..	..	..	..	57·14
Relation between order of tillering and death rate	Correlation Coefficient	+·78 P ·05	+·94 P ·01	+·84 $P < \cdot 01$	+·93 $P < \cdot 01$	+·97 P ·01	+·87 $P < \cdot 01$
	Regression coefficient	+9·55±3·11	+7·18±0·96	+1·58±·36	+15·69±2·48	+13·01±1·30	+4·21±0·77

Table III

1935

Order of tillering and percentage of deaths

Order of tillering	Date first recorded	Taungdeikpan			Ngasein		
		Htonsan	1 ft. × 1 ft.	2 ft. × 2 ft.	*Htonsan*	1 ft. × 1 ft.	2 ft. × 2 ft.
1	Main stem	20·59	16·66	0	33·33	16·66	8·33
2	26-8-35	19·45	13·79	40·00	40·74	18·75	12·00
3	2-9-35	47·62	14·81	10·53	47·62	7·69	6·25
4	9-9-35	50·00	15·62	20·83	77·77	28·57	6·66
5	16-9-35	None formed	34·48	17·50	85·71	11·11	12·12
6	23-9-35	50·00	25·00	31·71	75·00	63·63	5·88
7	30-9-35	33·33	75·00	23·53	None formed	83·33	11·63
8	7-10-35	..	100·00	27·45	100·00	45·45	8·69
9	14-10-35	..	..	12·50	100·00	100·00	29·79
10	21-10-35	..	..	46·15	..	..	45·83
11	28-10-35	..	..	..	..	..	66·66
Relation between order of tillering and death rate	Correlation Coefficient	+·53 $P < \cdot 1$	+·84 $P < \cdot 01$	+·43 $P < \cdot 1$	+·94 $P < \cdot 01$	+·81 P ·01	+·76 $P < \cdot 01$
	Regression coefficient	+3·30±2·64	+11·18±2·97	+2·00±1·47	+8·77±1·37	+10·00±2·69	+4·54±1·31

In Tables II and III the correlation and regression coefficients between the order of tiller formation and the death rates are given. Except for the 1935 Taungdeikpan closest and widest spacings all values of r are very high. The reason for the low values of r in *htonsan* planting is not clear but in the case of the 2 ft. × 2 ft. spacing there was an unusual loss of 40 per cent of the first tillers for an unapparent reason. If this high death rate for the first tillers is omitted, $r = +0{\cdot}74$, $P > 0{\cdot}01$ and $b = 3{\cdot}35 \pm 1{\cdot}17$.

The greater liability of tillers to die in the variety Ngasein than in Taungdeikpan is clear and also the very pronounced effect of spacing. This is also brought out by the numbers of tillers surviving to maturity, which average.

1934

(From Appendix Tables V to X)

Spacing	2 ft. × 2 ft.	1 ft. × 1 ft.	*Htonsan*
Taungdeikpan . .	23·9	15·7	8·7
Ngasein . . .	30·6	12·7	9·8

Fig. 4 of the regression lines for order of tillering and death rates in 1934 clearly shows the effect of spacing. The regression lines for the 1935 experiments are similar. It is probable that the relationship is not exactly represented by a straight line but the data do not warrant fitting polynomials. Only in the case of group planting do these regressions reach 100 per cent mortality whereas in the field the 1 ft. × 1 ft. spacing is restrictive enough to induce cent per cent deaths of late-formed tillers. At the widest spacing growth is terminated by flowering and drying of the soil before space becomes a limiting factor.

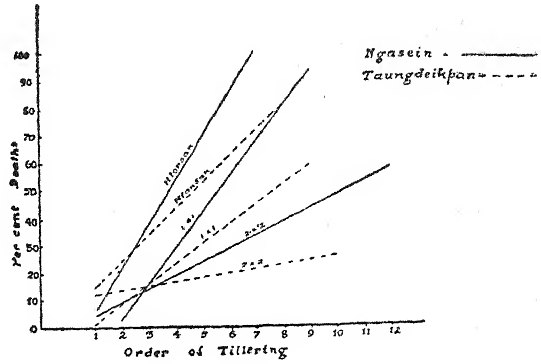

FIG. 4. Regression lines of order of tiller formation and death rates for Ngasein and Taungdeikpan in 1934

HEIGHT OF SEEDLING AND TILLERING

In 1932 the seedlings were not graded according to height and the experiments were planted with seedlings of mixed heights but of the same age. In any nursery, however carefully prepared, quite large differences in height and dry weight occur within the seedling population, probably due to spacing and fertility differences which cannot be avoided. The first records of height were made the day after transplanting and from these a rough classification into height groups was made. The seedling heights are compared in Table IV with the tillers formed 22 and 102 days from transplanting.

TABLE IV

Mean number of stems 22 and 102 days after transplanting (1932)

Height of seedlings (in cm.)	Ngakyi		Ngasein		Taungdeikpan		Paungmalaung	
	22 days from transplanting	102 days from transplanting	22 days from transplanting	102 days from transplanting	22 days from transplanting	102 days from transplanting	22 days from transplanting	102 days from transplanting
30—35 . . .	2·91	12·90	..	..	3·10	9·50	2·40	12·91
35—40 . . .	3·29	13·49	2·37	9·39	3·94	9·78	2·91	12·79
40—45 . . .	3·56	13·00	3·12	9·33	4·95	10·28	2·71	12·98
45—50 . . .	3·38	12·85	2·89	10·02	..	11·68	2·50	12·20
50—55 . . .	3·41	11·05	2·35	8·46	..	..	..	..
55—60 . . .	.	..	1·73	7·54	..	..	..	..
60 and over . .	.	..	1·71	6·22	..	..	..	..

In general, seedlings of medium height gave the largest number of tillers except for Taungdeikpan, but in that variety there were no tall seedlings.

More detailed experiments on height of seedlings were done in 1933 when four lengths of seedlings of two varieties were planted in 4 × 4 Latin squares and counts made fortnightly of stem numbers (Tables V and VI).

In both varieties the shortest seedlings have given the highest numbers of mature stems. The detailed records show that the taller seedlings tillered more rapidly than the shorter in the early stages but that the latter surpassed the former before the maximum tiller number was reached. Height of seedlings is therefore not a sure guide to vigour.

TABLE V

Ngasein—final stem numbers

Height of seedlings	25—30 cm. A	30—35 cm. B	35—40 cm. C	40 cm. and over D	Mean	S. E.
Mean of 4 plots . . .	9·78	9·36	8·48	8·43	9·01	0·083
Per cent of mean . . .	108·5	103·9	94·0	93·5	100·00	±0·921

z significant ($P<0·01$)
C. D. (5 per cent) = 0·287 or 3·187 per cent

A B C D

TABLE VI

Taungdeikpan—final stem numbers

Height of seedlings	25—35 cm. A	35—45 cm. B	45—55 cm. C	55 cm. and over D	Mean	S. E.
Mean of 4 plots . . .	10·72	9·55	9·03	8·66	9·49	0·308
Per cent of mean . . .	112·9	100·6	95·2	91·3	100·00	±3·247

z significant ($P<0·05$)
C. D. (5 per cent) = 1·067 or 11·236 per cent
A B C D

TABLE VII

Mean numbers of stems formed at different ages by seedlings of different heights ; varieties—Taungdeikpan and Ngasein, 1933

Height class	A		B		C		D	
Days from transplanting	Ngasein	Taungdeikpan	Ngasein	Taungdeikpan	Ngasein	Taungdeikpan	Ngasein	Taungdeikpan
0 . . .	1·00	1·00	1·00	1·10	1·00	1·14	1·08	1·43
11 . . .	1·03	1·08	1·02	1·19	1·03	1·28	1·09	1·41
25 . . .	1·55	2·50	1·80	2·60	1·88	3·69	2·25	3·25
39 . . .	4·24	6·71	4·99	6·80	4·95	7·68	5·88	7·38
53 . . .	9·15	12·32	10·08	11·59	9·32	11·45	10·18	11·39
67 . . .	11·60	14·39	12·30	12·75	11·13	11·83	11·83	11·47
81 . . .	14·03	15·47	13·91	12·86	12·29	11·53	12·14	11·09
95 . . .	12·83	12·69	12·05	11·03	11·05	10·16	10·76	9·61
109 . . .	9·78	10·72	9·37	9·55	8·48	9·03	8·42	8·66
Per cent deaths .	30·3	30·7	32·6	25·7	31·0	23·7	30·6	24·5

(Height classes as in Tables V and VI)

Fig. 5 shows the interpolated dates of formation of tillers T_1-T_8 for each class of seedling in both

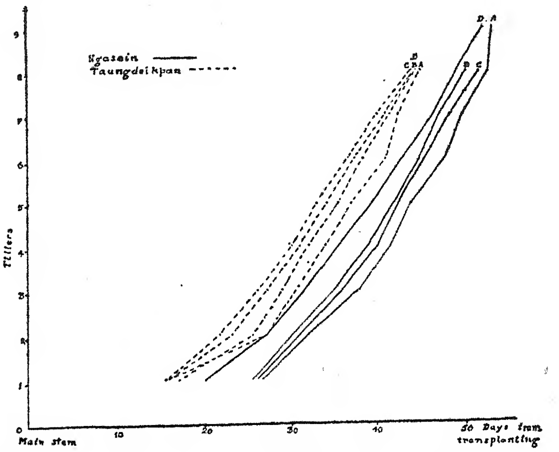

Fig. 5. Interpolated dates of formation of tillers 1-8 for four seedling sizes of Ngasein and Taundeikpan. (Not carried beyond T8 because deaths supervene at about that time)

varieties. The earlier tillering of Taungdeikpan is clearly brought out. In this variety the C class seedlings tillered first, being followed by D, B and A in that order. In Ngasein the tallest seedlings (D) tillered first followed by C, B and A in that order, so that in this case the taller the seedlings the earlier did it form tillers although it did not form so many.

Height of seedling and yield

The close connection between the yield and number of tillers matured leads to a corresponding influence of seedling size on yield of grain. The figures in Table VIII for yields of grain from 50 random plants from each plot in the preceding experiment show the influence of seedling height on yield.

These results are in agreement with the effect of seedling height on final tiller number, and show that small to medium size seedlings tiller more and yield better than tall ones. Birkinshaw [1940] states that the greatly increased growth in nurseries following manuring does not lead to increased yields in the field. The results here reported would seem to indicate that any advantage from the manuring of nurseries must come not from the greater size of the seedlings but from the earlier attainment of a size suitable for earlier transplanting, so leading through earlier commencement of tillering to enhanced yields.

Table VIII

Grain yields from seedlings of differenct heights ; Ngasein and Taungdeikpan, 1933

Seedling height class		A	B	C	D	Mean	S. E.	C. D. (5 per cent)
Ngasein	Mean of 4 plots	22·97	23·48	19·97	20·11	21·63	0·70	2·43
	Per cent	106·2	108·5	92·3	93·0	100·0	3·24	11·23
Taungdeik-pan	Mean of 4 plots	29·37	25·85	25·14	23·52	25·97	1·13	3·89
	Per cent	113·1	99·5	96·8	90·6	100·0	4·33	14·98

For values of A—D see Tables V and VI

Ngasein = B A D C

Taungdeikpan = A B C D

Early tillering

Since there is a high correlation between the order of a tiller and its liability to death (Tables II and III) the earlier a tiller is formed the better chance it has of surviving to contribute towards the yield. The linear regression coefficients of the number of stems formed by 2 September 1932 on final number matured are given below :

	b	
Ngakyi	3·61	$P < 0{\cdot}01$
Ngasein	3·15	
Taungdeikpan	2·88	
Paungmalaung	4·04	

These figures are derived from plots planted with seedlings of mixed size. In 1933 using plots planted with seedlings of uniform height the same relationship holds good for each size of seedling, giving the following linear regression coefficients :

		b
Taungdeikpan	A	$1\cdot02\pm0\cdot09$
	B	$0\cdot73\pm0\cdot04$
	C	$0\cdot61\pm0\cdot07$
	D	$0\cdot58\pm0\cdot04$
Ngasein	A	$1\cdot13\pm0\cdot09$
	B	$0\cdot78\pm0\cdot11$
	C	$0\cdot86\pm0\cdot36$
	D	$0\cdot69\pm0\cdot02$

(A—D as in Tables V and VI)

These coefficients are all much smaller than those for the 1932 crop and the Ngasein C class is not significant. For the rest the importance of early transplanting and a quick recovery from the damage of that operation is clear. Fig. 6 is for the Taungdeikpan A class seedlings. The others are similar and are not given here.

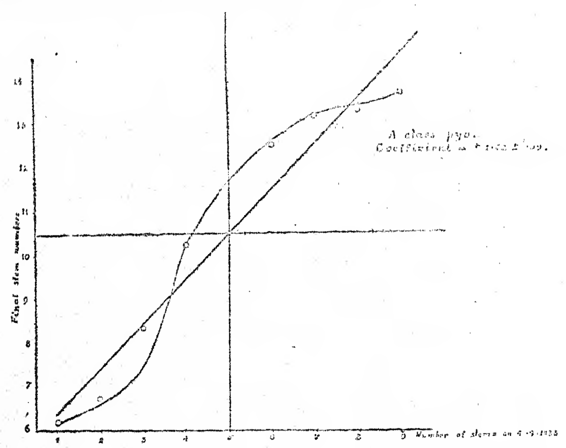

FIG. 6. Regression of early stem number on final stem number for Taungdeikpan in 1933

ORDER OF TILLERING AND WEIGHT OF PANICLE

Engledow and Wadham [1924] noted the tendency for weight of grains, straw and rachis to decrease in later-formed barley tillers. Our data for 1932 show a negative correlation between the number of stems per plant and the mean panicle weight.

	r	
Ngakyi	$-0\cdot384$	$P<10^{-8}$
Ngasein	$-0\cdot425$	„ 10^{-5}
Taungdeikpan	$-0\cdot304$	$P<10$

(Paungmalaung is omitted because of sparrow damage)

Although the correlations are highly significant the fact that the relationship is not linear has resulted in comparatively low figures for r, the polynomial curve being sigmoid.

Since the panicle weight is largely made up by the weight of grains it follows that the relationship between the order of tillering and the number of filled grains per panicle will represent the effect of the order of the tiller on its contribution towards the final yield (Table IX).

These figures show that the later a tiller is formed the fewer good grains it matures, an additional reason for promoting early tillering as much as possible.

From the regression coefficients it appears that for Taungdeikpan a delay of one week in tiller formation may reduce the number of grains matured by 11 to 13 and for Ngasein from $3\cdot7$ to $9\cdot7$. In both varieties the crowding effect at the closer spacing is very evident.

In 1935 these experiments were repeated with the addition of group planting (*htonsan*). The correlations between order of tillering expressed as the number of days from sowing to date of recording the tiller and the mean panicle weight were very high.

	Htonsan	1 ft. × 1 ft.	2 ft. × 2 ft.
Taungdeikpan	$-0\cdot96$	$-0\cdot91$	$-0\cdot98$
Ngasein	$-0\cdot96$	$-0\cdot98$	$-0\cdot99$

TABLE IX

Correlation and regression coefficients between order of tillering and mean number of good grains per panicle 1933 and 1934

Plant spacing	Taungdeikpan				Ngassein			
	Correlation coefficient r		Regression coefficient b		Correlation coefficient r		Regression coefficient b	
	1933	1934	1933	1934	1933	1934	1933	1934
1 ft. × 1 ft.	$-\cdot93$ $P<\cdot01$	$-\cdot89$ $P<\cdot01$	$-13\cdot89\pm1\cdot73$	$-12\cdot48\pm3\cdot02$	$-\cdot70$ $P<\cdot01$	$-\cdot98$ $P<\cdot01$	$-9\cdot73\pm2\cdot66$	$-8\cdot41\pm\cdot73$
2 ft. × 2 ft.	$-\cdot91$ $P<\cdot01$	$-\cdot98$ $P<\cdot01$	$-11\cdot22\pm1\cdot25$	$-13\cdot62\pm0\cdot88$	$-\cdot88$ $P<\cdot01$	$-\cdot99$ $P<\cdot01$	$-3\cdot80\pm0\cdot60$	$-6\cdot75\pm\cdot31$

Whether the relationship is expressed as between order of tillering and panicle weight, as above, or order of tillering and grain weight is immaterial, since in both cases the correlations are high. The regression coefficients corresponding to these data vary little and average for the six sets 0·035, that is to say a delay of one day in tiller formation will entail a loss in panicle weight of 0·035 gm. on average.

Not only does delay in tiller formation result in a drop in mean panicle weight and mean weight of grain per panicle but it also leads to a reduction in individual grain size at close spacings. In Table X the mean weights of grains from early and late tillers are given.

TABLE X

Comparison of grain weights (gm.) from early and late tillers

	Mean wt. Early tillers	Mean wt. Late tillers	S. E. difference	Significance
Taungdeikpan—				
1 ft. × 1 ft.	·0184	·0172	±·00048	S
2 ft. × 2 ft.	·0178	·0176	±·00020	NS
Ngasein—				
1 ft. × 1 ft.	·0262	·0246	±·00038	S
2 ft. × 2 ft.	·0263	·0258	±·00026	NS

At the closer spacing the weight of the grains on early tillers is significantly greater but in the case of the wider-spaced plants the difference is too small to be relied on. Where space is limited it may be concluded that heavier grain is borne on the earlier tillers, which at the same time bear more grains. The major contribution towards the yield therefore comes from the earlier tillers because these have a greater survival value and bear heavier panicles with larger grains. In Table XI the percentage of the total grain yield contributed by the tillers recorded at weekly intervals are shown and the general decline in the fruitfulness of the later-formed tillers is clear. (It is not possible with paddy to record each tiller in order of formation, as has been done for wheat, because often two or more tillers are formed at nearly the same time).

Besides the declining importance of later tillers the effect of crowding is to concentrate a greater proportion of the yield in the main stems and early tillers. Whereas only 10-13 per cent of the yield is contributed by the main stems at 2 ft. × 2 ft. spacing, over 20 per cent is accounted for at the *htonsan* spacing. This *htonsan* method of planting, however, comprises four to seven plants in a group, that is to say four to seven main stems, but even so the increasing contribution by main stems or early tillers with closer spacing is clear. It is therefore to be expected that anything which will promote early commencement of tillering after transplanting is likely to promote yield. This may be effected by such methods as early transplanting (which requires nursery operations to provide good seedlings at an early date), application of quick-acting fertilizers which will promote a quick onset of tillering and a planting distance which will not cause overcrowding at an early stage.

TABLE XI

Order of tillering and percentage yield (in weight) of grains

(Mean of 12 plants)

(Sown on 16-6-34. Transplanted on 27-7-34)

Recording dates	Ngasein		Taungdeikpan		
	Htonsan	2 ft. × 2 ft.	*Htonsan*	1 ft. × 1 ft.	2 ft. × 2 ft.
Main stems	21·9	10·4	20·0	14·6	12·8
13-8-34	19·5	11·8	19·2	13·8	14·0
20-8-34	17·3	11·4	19·7	14·0	13·0
27-8-34	15·5	11·1	14·6	10·8	10·6
3-9-34	15·4	10·2	9·9	9·8	10·3
10-9-34	10·4	9·5	10·1	8·7	9·5
17-9-34	..	8·9	6·5	8·2	9·1
24-9-34	..	8·1	..	9·7	8·1
1-10-34	..	7·2	..	7·5	7·0
8-10-34	..	6·0	..	..	5·6
15-10-34	..	5·4	..	..	..

(Ngasein 1 ft. × 1 ft. omitted owing to an error in the records which are now not available)

In Table XII the regressions are calculated to show the delay in flowering for each week's delay in tiller formation. The figures show that in round numbers a delay of one week in tiller formation at 1 ft. × 1 ft. spacing entails a delay of 0·55 day in flowering while at 2 ft. × 2 ft. spacing this delay increases to about 0·74 day. Since as long as 11 weeks may intervene between the dates of formation of the first and last tillers, the flowering would, on these results, spread over about eight days. The flowering does, in fact, extend over about nine or ten days. The greater delay in flowering of late tillers at the wider spacing is due, in part at least, to the longer period over which tillers capable of flowering continue to be produced, and in part to the crowding effect at the closer spacing which always induces earlier flowering.

ORDER OF TILLERING AND FLOWERING DATE

TABLE XII

Correlations and regressions between date of formation and date of flowering of tillers

—		1933		1934	
		r Correlation coefficient	*b* Regression coefficient	*r* Correlation coefficient	*b* Regression coefficient
Taungdeikpan	1 ft. × 1 ft.	+·60±·067	+·56±·062	+·42±·068	+·69±·113
,,	2 ft. × 2 ft.	+·56±·045	+·81±·064	+·47±·044	+·84±·077
Ngasein	1 ft. × 1 ft.	+·57±·074	+·57±·073	+·27±·083	+·42±·128
,,	2 ft. × 2 ft.	+·65±·043	+·85±·057	+·44±·048	+·47±·052

SUMMARY

Tillering begins about a fortnight after transplanting and the rate quickly reaches a maximum, after which a steady decline sets in until by the beginning of November only a small number of tillers are produced.

Tiller deaths commence about the beginning of October at close spacing, somewhat later at wider spacing, and the death rate tends to increase as the season advances. The tillering shows modes which closely correspond in the different varieties and at different spacings indicating some common influencing factor. The rainfall in 10-day totals exhibits similar modes but preceding the tillering modes by about 15 days. It is suggested that the two phenomena are interconnected.

The liability of tillers to premature death is shown to increase as the recording date advances until at close spacing the late-formed tillers have no chance of surviving. At the 2 ft. × 2 ft. spacing all tillers have some chance of reaching maturity. There does not appear to be any critical period of tillering such as the Cambridge workers found for wheat and barley. The liability to premature death is not confined to the late-formed tillers only, but death may occur to the main stem itself or any other stems. With group planting as many as 20 per cent of the main stems may die prematurely.

It is not necessarily the tallest seedlings which tiller and yield best. It was found that in general the shortest seedlings gave the largest number of surviving tillers at harvest, and because of the close relationship between tillering and yield, these gave the greatest final yield. The tallest seedlings formed tillers most rapidly in the early stages but did not mature as many as the shorter ones.

The earlier a tiller is formed the better its chance of surviving to contribute to the yield. Early transplanting may therefore be expected to enhance yield and manuring of nurseries to bring seedlings to a transplantable size at an early date will be beneficial.

The later a surviving tiller is formed the smaller is the share of the total yield contributed by it, because the panicle weight, the number of filled grains and the mean grain weight progressively decline as the tillering date advances. Crowding tends to concentrate a larger portion of the total yield in the main stems and early tillers.

The correlation between date of formation of a tiller and the date of its flowering is definite, a delay of one week in tillering postponing flowering on average about half to three-quarters of a day.

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APPENDIX

Tables of summed stem numbers for 12 plants selected at random, 1933

TABLE I

Record of tillers (including main stems) 1933

Theikpan Taungdeikpan 1 ft. × 1 ft. spacing. Transplanted on 3-8-1933

	15th Aug. 1	22nd Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	10th Nov. 15	14th Nov. 16
Total tillers formed	*	35	*	34	17	*	29	24	*	21	14	6	3	1	1	1
Progressive total	*	35	*	69	86	*	115	139	*	160	174	180	183	184	185	186
Deaths	*	...	*	...	...	*	...	...	*	1	2	7	3	2	8	3
Number survived	*	35	*	69	86	*	115	139	*	159	171	170	170	169	162	160

* Counts not taken

TABLE II

Record of tillers (with main stems) 1933

Ngasein C401 2 ft. × 2 ft. spacing. Transplanted on 28-7-1933

	15th Aug. 1	21st Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	14th Nov. 15	20th Nov. 16	24th Nov. 17	30th Nov. 18	8th Dec. 19
Total tillers formed	35	*	35	50	45	23	46	58	27	23	39	15	8	4	24	4	2	4	1
Progressive total	35	*	70	120	165	188	234	292	319	342	381	396	404	408	432	436	438	442	443
Deaths	...	...	...	...	...	...	...	...	...	5	9	16	29	22	13	14	1	1	5
Number survived	35	*	70	120	165	188	234	292	319	337	367	366	345	327	338	328	329	332	328

* Counts not taken

TABLE III

Record of tillers (with main stems) 1933

Ngasein C401 1 ft. × 1 ft. spacing. Transplanted on 3-8-1933

	15th Aug. 1	21st Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	10th Nov. 15	14th Nov. 16	20th Nov. 17	24th Nov. 18	8th Dec. 19
Total tillers formed	*	29	*	17	21	*	24	15	*	21	31	6	8	1	*	4	2	1	1
Progressive total	*	29	*	46	67	*	91	106	*	127	158	164	172	173	*	177	179	180	181
Deaths	...	...	...	...	...	...	...	...	...	...	1	13	12	6	*	3	1	2	0
Number survived	*	29	*	46	67	*	91	106	*	127	157	150	146	141	*	142	143	142	143

* Counts not taken

TABLE IV

Record of tillers with main stems (Sums of 12 plants) *1933*

Theikpan Taungdeikpan 2ft. × 2ft. spacing. Transplanted on 28-7-1933

	15th Aug. 1	22nd Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	9th Nov. 15	14th Nov. 16	20th Nov. 17	30th Nov. 18	8th Dec. 19
Total tillers formed	34	...	29	61	34	14	62	66	48	21	43	17	6	4	0	8	1	0	0
Progressive total	...	...	63	124	158	172	234	300	348	369	412	429	435	439	439	447	448	448	448
Deaths	...	...	...	...	...	...	...	...	...	...	3	5	11	22	17	13	13	5	5
Number survived	34	...	63	124	158	172	234	300	348	369	409	421	416	398	381	376	364	359	354

TABLE V

Ngasein 2 ft. × 2 ft. 1934

Totals of 12 plants

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	13th Nov. 15	19th Nov. 16	26th Nov. 17	30th Nov. 18	8th Dec. 19
Total tillers formed	12	22	25	55	71	51	74	48	45	44	40	7	...	...	...	...	...	...	...
Progressive total	12	34	59	114	185	236	310	358	403	447	487	494	...	...	...	...	...	...	...
Deaths	...	...	...	...	...	...	2	3	4	4	10	12	38	34	2	14	3	0	1
Number Survived	12	34	59	114	185	236	308	353	394	434	464	459	421	387	385	371	368	368	367

TABLE VI

Ngasein 1 ft.×1 ft. 1934

Totals of 12 plants

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	13th Nov. 15	19th Nov. 16	26th Nov. 17	8th Dec. 18
Total tillers formed	12	15	21	44	54	36	26	15	3	3	2	0	1	...	...	...	...	...
Progressive total	12	27	48	92	146	182	208	223	226	229	231	231	232	...	...	...	...	...
Deaths	...	...	...	...	...	...	2	1	26	5	26	1	10	2	3	3	0	1
Number survived	12	27	48	92	146	182	206	220	197	195	171	170	161	159	156	153	153	152

TABLE VII

Ngasein htonsan 1934

Totals of 12 groups

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	13th Nov. 15	19th Nov. 16	26th Nov. 17
Total tillers formed	*32	36	42	43	31	11	5	1	0	2	...	...	...	...	...	...	...
Progressive total	32	68	110	153	184	195	200	201	201	203	...	...	...	...	...	...	...
Deaths	...	...	...	...	...	3	5	8	26	3	21	3	7	8	2	2	...
Number survived	32	68	110	153	184	192	192	188	162	161	140	137	130	122	120	118	...

*Mean number of plants per hill = 2·51

TABLE VIII

Taungdeikpan 2 ft.×2 ft. 1934

Totals of 12 groups

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	12th Nov. 15	19th Nov. 16
Total tillers formed	12	28	37	68	73	54	60	89	65	38	3	2	...	...	...	...
Progressive total	12	40	77	145	218	272	332	421	486	524	527	529	...	...	...	...
Deaths	...	...	...	...	...	2	5	1	3	1	14	15	19	23	12	7
Number survived	12	40	77	145	218	270	325	413	475	512	501	488	469	446	414	407

TABLE IX

Taungdeikpan 1 ft.×1 ft. 1934

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	12th Nov. 15	19th Nov. 16
Total tillers formed	12	26	26	51	51	33	35	28	2	2	4	...	...	...	...	...
Progressive total	12	38	64	115	166	199	234	262	264	266	270	...	...	...	...	...
Deaths	...	...	...	...	1	0	4	3	17	4	23	4	14	4	4	3
Number survived	12	38	64	115	165	198	229	254	239	237	218	214	200	196	192	189

TABLE X

Taungdeikpan htonsan 1934

Totals of 12 groups

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14
Total tillers formed	*25	48	32	26	12	9	4	5	0	1	...	...	...	...
Progressive total	25	73	105	131	143	152	156	161	161	162	...	...	...	...
Deaths	...	...	...	1	5	3	8	12	8	2	8	2	4	4
Number survived	25	73	105	130	137	143	139	132	124	123	115	113	109	105

* Mean number of plants per hill = 2·09

A STUDY OF THE CHANGES IN THE QUALITY OF PUNJAB-AMERICAN 289F/43 COTTON WITH VARIATIONS IN THE DATES OF SOWING AND WITH PROGRESSIVE PICKINGS*

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(Received for publication on 18 May 1942)

The date of sowing has a very important bearing on the development and yield of the cotton plant and literature abounds in instances where a change in the normal dates of sowing has been instrumental in increasing the yield or protecting the crop from the attack of insect pests and diseases.

In the early days of the introduction of American cotton in the Punjab the best time of sowing was considered to be from the end of March to the end of April. As time went on and more critical experiments were performed, a tendency for shifting the dates of sowing became evident. The periodic partial failures of American cotton accentuated this tendency towards later sowing as it was observed that late-sown cotton suffered less from *tirak* (bad opening of bolls) than the early-sown crop [Anonymous, 1937]. The Department of Agriculture, Punjab, now recommends 15 May to 15 June as the optimum period for sowing cotton in a major portion of the Canal Colonies and from the end of May to the end of June in the south-western districts of the province. The zemindars of these tracts have not been slow in acting on this recommendation and had, in fact, come to the same conclusion almost simultaneously with the Departmental workers in the early thirties. It has also been established that American cotton sown before the optimum period suffers more from *tirak*. In order, however, to get a quantitative idea of the effect of either early, normal or late sowing and the time of picking of the crop on fibre-properties properly laid out experiments have been carried out and the present paper deals with the data obtained from these experiments.

Previous literature

It is not proposed to review the previous literature on the field behaviour of the crop sown at different times. References on the effect of date of sowing on fibre-properties are unfortunately lacking except that of a former worker in the Cotton Research Laboratory, Lyallpur [Sen, 1934, 1], who did not find any change in the length and fineness of the fibre of Punjab-American 4F and 289F/43 when sown on 15 April, 5 May, 20 May and 3 June. The study on P.-A. 289F/43 has now been pursued further by including a larger variation in the dates of sowing combined with progressive pickings and by determining a larger number of fibre characters.

Material and method

P.-A. 289F/43 was sown in 1937 in randomized blocks using five dates of sowing and seven replications. The dates of sowing were: 15 April, 5 May, 20 May, 4 June and 1 July. The following procedure was adopted for collecting the samples:

Four normal plants were selected at random from each bed in the beginning of the picking season. All the well-opened bolls on these four plants were picked every week in separate bags. Pickings were made on the same day of the week in all the beds throughout the season. Pickings commenced on 27 September 1937 in the case of the first, second, third and the fourth sowing dates and 1 November 1937 in the case of the fifth sowing date and continued at weekly intervals up to 10 January 1938 in all cases.

The *kapas* picked from all the beds under the same sowing date was mixed for each picking and ginned. This procedure reduced the number of samples to within a workable limit. At the time of fibre tests, the samples of the first picking (27 September 1937) from the first, second, third and the fourth sowing dates were not tested for fibre characters as there was an uncertainty in the period during which the bolls picked on this date had opened; the samples from the last picking (10 January 1938) of all sowings were also not tested as the quantity of lint available in this case was very small. The remaining 66 samples, representing 14 pickings each of the first four sowing dates and 10 pickings of the fifth sowing, were available for testing.

Slivers were prepared by the usual sampling methods, drafted, cleaned and redrafted with the Balls sorter draw-box and were used for the determination of the following fibre characters:

(1) Balls sorter mean length
(2) Balls sorter modal length
(3) Balls sorter fibre-length irregularity (per cent)
(4) Mean fibre-weight per unit length
(5) Percentage of mature fibres and
(6) Highest standard warp counts.

*Read at the Indian Science Congress, Baroda, January 1942

TABLE I

Picking date	Sowing date					Sowing date					Sowing date				
	I (15.4.37)	II (5.5.37)	III (20.5.37)	IV (4.6.37)	V (1.7.37)	I (15.4.37)	II (5.5.37)	III (20.5.37)	IV (4.6.37)	V (1.7.37)	I (15.4.37)	II (5.5.37)	III (20.5.37)	IV (4.6.37)	V (1.7.37)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	(*a*) Balls sorter mean length (cm.)					(*b*) Balls sorter modal length (cm.)					(*c*) Fibre length irregularity (per cent)				
4.10.37	2·15	2·24	2·32	2·26	..	2·39	2·56	2·63	2·55	..	25·6	25·3	23·0	25·2	..
11.10.37	2·14	2·35	2·35	2·39	..	2·36	2·65	2·65	2·68	..	22·3	24·3	23·6	24·0	..
18.10.37	2·08	2·32	2·18	2·19	..	2·20	2·60	2·42	2·37	..	25·2	25·4	26·4	23·3	..
25.10.37	2·11	2·29	2·13	2·30	..	2·15	2·52	2·29	2·61	..	21·7	25·0	23·0	27·6	..
1.11.37	2·11	2·29	2·24	2·37	2·16	2·13	2·56	2·46	2·63	2·31	21·8	25·6	24·3	24·8	23·8
8.11.37	2·06	2·25	2·21	2·26	2·20	2·07	2·49	2·37	2·55	2·33	20·4	26·4	24·1	27·7	23·3
15.11.37	2·11	2·35	2·28	2·28	2·20	2·20	2·59	2·58	2·50	2·41	21·8	23·2	24·3	24·7	25·6
22.11.37	2·00	2·18	2·22	2·35	2·30	2·05	2·40	2·42	2·56	2·55	22·4	26·0	21·8	24·2	26·6
29.11.37	2·02	2·26	2·22	2·28	2·34	2·05	2·51	2·42	2·61	2·60	20·6	25·4	24·5	27·9	25·2
6.12.37	1·92	2·20	2·31	2·31	2·26	2·00	2·40	2·60	2·60	2·44	22·5	24·8	23·8	23·7	24·1
13.12.37	2·22	2·24	2·20	2·24	2·30	2·42	2·45	2·40	2·44	2·56	24·8	23·6	23·4	23·2	26·1
20.12.37	1·92	2·04	2·12	2·09	2·14	1·95	2·16	2·26	2·14	2·25	22·9	24·8	22·6	22·7	22·0
27.12.37	1·83	2·01	1·96	2·14	1·98	1·76	2·06	1·98	2·26	2·05	17·1	20·7	21·0	19·4	23·7
3.1.38	1·79	2·03	2·06	2·10	1·84	1·83	2·04	2·13	2·21	1·83	21·6	20·8	23·6	22·5	21·7
	(*d*) Mean fibre weight per unit length (10—6 gm./cm.)					(*e*) Percentage of mature fibres					(*f*) Highest standard warp counts (calculated)				
4.10.37	0·96	1·16	1·16	1·23	..	23	20	24	27	..	38·7	39·0	41·4	39·1	..
11.10.37	1·25	1·30	1·33	1·37	..	27	31	31	26	..	35·2	41·0	40·8	40·8	..
18.10.37	1·15	1·25	1·18	1·05	..	20	34	26	15	..	33·5	40·7	36·4	38·4	..
25.10.37	0·96	1·26	1·23	1·30	..	25	32	36	40	..	37·7	40·1	35·7	40·2	..
1.11.37	0·92	1·21	1·24	1·22	1·26	26	34	41	34	36	38·2	41·0	39·0	42·9	36·6
8.11.37	1·00	1·33	1·26	1·33	1·22	25	47	34	35	30	35·6	39·0	37·6	38·0	37·1
15.11.37	1·12	1·36	1·41	1·45	1·34	19	43	45	34	34	34·3	41·0	38·8	37·0	36·5
22.11.37	0·94	1·26	1·42	1·31	1·24	16	38	46	38	30	33·7	36·8	36·8	41·1	40·3
29.11.37	1·06	1·33	1·27	1·36	1·35	12	35	42	43	32	31·9	37·9	38·5	39·1	40·2
6.12.37	0·91	1·19	1·41	1·35	1·18	9	35	49	37	27	30·7	38·3	39·6	39·5	39·9
13.12.37	1·27	1·17	1·33	1·29	1·20	27	41	41	41	25	36·7	40·4	37·3	38·7	39·9
20.12.37	0·98	1·16	1·21	1·32	1·20	13	26	31	38	14	30·9	33·4	35·2	33·3	34·3
27.12.37	0·84	1·14	1·20	1·21	1·00	3	18	14	23	9	27·9	32·6	28·8	35·2	31·0
3.1.38	0·98	1·01	1·10	1·10	0·74	7	13	20	16	1	25·7	33·3	34·6	35·1	29·4

The methods followed in the determination of the first four characters were the same as described by Ahmad [1933] and in the determination of the percentage of mature fibres, the method of Gulati and Ahmad [1935] was adopted using their new device for mounting fibres [Ahmad and Gulati, 1936]. The above five fibre characters were converted into a quantity 'highest standard warp counts' (H. S. W. C.) according to an equation given recently by Ahmad [1941]. The calculated H. S.W.C. served to express the results of fibre-tests as a single quantity suited to quantitative analysis. The data obtained for the five fibre characters as well as the H. S. W. C. calculated therefrom are presented in Table I.

Analysis of results

(*a*) The values of fibre characters of samples from the fifth sowing date are not included in the analysis given below mainly because the first picking from this sowing date was available only on 1 November 1937 and not on 27 September 1937 as in the case of the other four sowing dates.

There were 14 pickings in each of the first four sowing dates and analysis of variance could be applied to the six sets of 56 observations each of the six fibre characters taking one set after another. The values of mean squares and their significance obtained from this analysis are set out in Table II. It will be seen from Table II that the variances due to sowing dates were highly significant in respect of all fibre characters, excepting the fibre-length irregularity in which case also the significance was nearly at 2 per cent level, showing in general a real variation in all the fibre characters studied with a variation in sowing date.

From the table of mean values (Table III) it is apparent that the fibre characters of samples from the first sowing date were all significantly lower than those of samples from the other three sowing dates, which did not vary significantly among themselves.

TABLE II

Values of mean square

Source of variation	D. F.	Mean fibre-length	Modal length	Fibre-length irregularity	Mean fibre-weight per unit length	Percentage of mature fibres	Highest standard warp counts (calculated)
Sowing dates .	3	0·1350827**	0·3834684**	14·71494*	0·1964066**	775·0714**	69·4369**
Residual .	52	0·0123435	0·0360345	3·68454	0·0117257	87·9368	10·2024

*Significant at 5 per cent level
**Significant at 1 per cent level

TABLE III

Mean values of fibre characters of the I, II, III and IV sowing dates

Fibre character	Sowing date I (15-4-37)	Sowing date II (5-5-37)	Sowing date III (20-5-37)	Sowing date IV (4-6-37)	Critical difference between two means
1. Mean fibre-length (cm.)	2·033	2·218	2·200	2·254	±0·0891
2. Modal length (cm.)	2·111	2·428	2·401	2·479	±0·1522
3. Fibre-length irregularity (per cent) . .	22·19	24·38	23·53	24·35	±1·539
4. Mean fibre-weight per unit length (10^{-6} gm/cm.)	1·024	1·224	1·268	1·278	±0·0868
5. Percentage of mature fibres . . .	18·00	31·93	34·29	31·93	±7·519
6. Highest standard warp counts (calculated)	33·62	38·18	37·18	38·46	±2·5607

The conclusion drawn from the above analysis was that the first sowing date, as early as about the third week of April, was not desirable from considerations of lint quality. The second sowing date had not, in this year, produced lint of a quality any different from that of the third and the fourth sowing dates, which, *inter se*, did not show any significant difference in the quality of lint.

(*b*) As the first picking in the fifth sowing date was available only on 1 November 1937, the fibre characters of pickings from this sowing could not be included in the above analysis of variance for the study of variation in lint quality with changes in sowing dates. The following method was, therefore, adopted to compare the lint quality of pickings from the fifth sowing with that of pickings from the other sowings. No rigorous

validity is claimed for the method which was used only in the absence of a better one.

The average in each picking of values of fibre characters of samples from the second, third and the fourth sowing dates, in all pickings made on and after 1 November, was compared with the fibre characters of the corresponding pickings from the fifth sowing date by the method quoted by Tippett [1937]. The working is given in detail in Table IV for mean fibre-length only for purposes of illustration and the compiled mean values of fibre characters and the significances of the differences between them are brought out in Table V.

TABLE IV

Date of picking	Mean fibre-length (cm.)		Difference d	Sums of squares of d measured as deviations from $\bar{d}=0\cdot0934$
	Average value for the II, III and the IV sowing dates	Value for the V sowing date		
1-11-37	2·30	2·16	0·14	
8-11-37	2·24	2·20	0·04	
15-11-37	2·30	2·20	0·10	
22-11-37	2·25	2·30	−0·05	
29-11-37	2·25	2·34	−0·09	
6-12-37	2·27	2·26	0·01	
13-12-37	2·23	2·30	−0·07	
20-12-37	2·08	2·14	−0·06	
27-12-37	2·04	1·98	0·06	
3-1-38	2·06	1·84	0·22	
Sums	22·02	21·72	0·30	

$$t=\frac{\bar{d}}{\frac{S}{\sqrt{N}}}=\frac{\frac{0\cdot30}{10}}{\sqrt{\frac{0\cdot0934}{9}}\times\frac{1}{\sqrt{10}}}$$

$=0\cdot9312$ and $n=9$

The above t is non-significant

TABLE V

Fibre character	Mean value		Difference (col. 2-col. 3).	D. F.	
	Of averages for the II, III and IV sowing dates	For the V sowing date			
1	2	3	4	5	6
1. Mean fibre-length (cm.)	2·202	2·172	0·03	9	0·9312
2. Modal length (cm.)	2·393	2·333	0·06	9	1·2696
3. Fibre-length irregularity (per cent)	23·86	24·21	—0·35	9	0·5400
4. Mean fibre-weight per unit length 10^{-6} gm./cm.)	1·265	1·173	0·092	9	2·7020*
5. Percentage of mature fibres	34·4	23·8	10·6	9	6·4596**
6. Highest standard warp counts (calculated)	37·33	36·52	0·81	9	1·037

*Significant at 5 per cent level

**Significant at 1 per cent level

It was found that, while the differences in mean fibre-length, modal length and fibre-length irregularity were all non-significant, the difference in mean fibre-weight per unit length was significant and that in the percentage of mature fibres highly so. The difference in the calculated H. S. W. C., however, was not significant. This might be due to the following reasons. The total correlation coefficient [Ahmad, 1941] between H. S. W. C. and mean fibre-length is as high as $=+0\cdot878$ when compared with that between H. S. W. C. and mean fibre-weight per unit length, viz. $r=-0\cdot812$ and that between H. S. W. C. and percentage of mature fibres, viz. $r=-0\cdot319$. Hence the non-significant difference in the mean fibre-length probably masked the effect of the significant differences in mean fibre-weight per unit length and percentage of mature fibres.

From a study of differences in fibre characters from picking to picking, expressed as the excess of the average of the second, third and the fourth sowing dates over the fifth sowing date, it was

found that the mean fibre-weight per unit length and the percentage of mature fibres in pickings from the fifth sowing date were uniformly lower than those in pickings from the second, third and the fourth sowing dates in each picking individually, excepting the mean fibre-weight per unit length of pickings from 1 and 29 November. The mean fibre-length and characters derived therefrom as well as the calculated H. S. W. C. were not so consistently different. This showed that the significantly lower mean fibre-weight and percentage of mature fibres in pickings from the fifth sowing date were not only an aggregate effect but true in each individual picking.

These results indicated that the quality of lint in pickings from the fifth sowing date was, on the aggregate, similar to that of lint in corresponding pickings from the second, third and the fourth sowing dates mainly because of the non-significant difference in mean fibre-length, which rendered the difference in calculated H. S. W. C. also non-significant by masking the effect of the significant differences in mean fibre-weight per unit length and percentage of mature fibres. But the lower percentages of mature fibres in pickings from the fifth sowing date would certainly detract from the quality of the yarn spun from these pickings by introducing such factors as neppiness which are known to be caused, *inter alia*, by immature fibres.

Variations in lint with progressive pickings

The values of fibre characters of pickings from the first sowing date were omitted from further considerations due to their low lint quality and analysis of variance was again applied to values of fibre characters of pickings from the second, third and the fourth sowing dates only. The total sum of squares in this analysis was traced to three sources of variation, viz.

(1) variations due to sowing dates,
(2) variations due to pickings, and
(3) residual variations.

The mean square due to sowing dates (Table VI) was non-significant with respect to all fibre characters, excepting that due to mean fibre-length which was just significant at 5 per cent level. This result further confirmed that obtained previously (Table III) that, between themselves, the second, third and the fourth sowing dates did not differ significantly in the quality of lint. This observation was brought out clearly when, as in Table VII of mean values, the critical difference between two values was calculated using the mean square due to residual in this analysis.

TABLE VI

Values of mean square

Source of variation	D. F.	Mean fibre-length	Modal length	Fibre-length irregularity	Mean fibre-weight per unit length	Percentage of mature fibres	Highest standard warp counts (calculated)
Sowing dates	2	0·010716*	0·022306	3·25575	0·01168215	25·93575	6·32475
Pickings	13	0·027493**	0·089670**	6·54011**	0·0232434**	229·52857**	20·19531**
Residual	26	0·002945	0·007903	1·76533	0·0035475	28·57033	2·84040

* Significant at 5 per cent level
**Significant at 1 per cent level

TABLE VII

Mean values of fibre characters in the second, third and the fourth sowing dates

Sowing date	Mean length (cm.)	Modal length (cm.)	Fibre-length irregularity (per cent)	Mean fibre-weight per unit length (10^{-6} gm./cm.)	Percentage of mature fibres	Highest standard warp counts (calculated)
1	2	3	4	5	6	7
II (5-5-37)	2·22	2·43	24·3	1·224	31·9	38·18
III (20-5-37)	2·20	2·40	23·5	1·268	34·3	37·18
IV (4-6-37)	2·25	2·48	24·3	1·278	31·9	38·46
Critical difference	±0·0435	±0·0713	±1·065	±0·0478	±4·3	±1·35

The above conclusion that the samples from the second, third and the fourth sowing dates did not show any significant difference among themselves justified the procedure adopted below in considering the variations in fibre characters from picking to picking. The average in each picking of the three values of each fibre character of samples from the second, third and the fourth sowing dates could be treated as the fibre character of that picking. This procedure would also be in consonance with general agricultural practice in the Canal Colonies where the sowing of cotton is distributed, as already mentioned, over a fairly extended period, from the third week of May to the second week of June, and any study of variations in lint quality with progressive pickings must allow for that practice. This study would therefore be more representative of actual agricultural practice than studies of a similar nature which have been previously conducted by Ayyar and Rao [1930], Rao [1933] and Sen [1934, 2] in each of which the sowing was done on a stipulated day and pickings were made at suitable intervals.

The mean square due to pickings (Table VI) was highly significant in the case of all the six fibre characters thus indicating, in aggregate, a real variation in fibre characters due to variation in the time of picking. In Table VIII are given the mean values of the fibre characters for each picking. Considering the length values, it was found that the mean fibre-length remained almost constant, within the limits of variability, in all the pickings from 4 October to 13 December, 1937; thereafter it showed a sudden and significant fall. The modal length and fibre-length irregularity, being characters derived from mean fibre length, showed a similar trend. Much importance is not to be attached, however, to the fall in fibre-length irregularity, which ordinarily would be desirable but, being in this case associated with a fall in the mean fibre-length, did not connote any real improvement in quality. The mean fibre-weight per unit length, after fluctuating a little during the first three pickings, ceased to show any significant difference from picking to picking up to 20 December, after which it fell. The percentage of mature fibres closely followed the variations in the mean fibre-weight per unit length. It must, however, be mentioned that the fall in the mean fibre-weight per unit length, being here associated with a fall in maturity, did not indicate an improvement in lint quality, which it otherwise would, had not maturity also varied. The calculated H. S. W. C. remained constant within the limits of variability in all pickings from 4 October to 13 December, 1937. Thereafter it showed a significant deterioration. On the whole, it could be stated that, while the lint quality did not show any significant difference from picking to picking up to about the middle of December, there was a sudden fall therafter.*

TABLE VIII

Mean values of fibre characters in progressive pickings

Date of picking 1	Mean length (cm.) 2	Modal length (cm.) 3	Fibre-length irregularity (per cent) 4	Mean fibre weight per unit length (10^{-6} gm./cm.) 5	Percentage of mature fibres 6	Highest standard warp counts (calculated) 7
4-10-37	2·27	2·58	24·5	1·18	23·7	39·83
11-10-37	2·36	2·66	24·0	1·33	29·3	40·87
18-10-37	2·23	2·46	25·0	1·16	25·0	38·50
25-10-37	2·24	2·47	25·2	1·26	36·0	38·67
1-11-37	2·30	2·55	24·9	1·22	36·3	40·97
8-11-37	2·24	2·47	26·1	1·31	38·7	38·20
15-11-37	2·30	2·56	24·1	1·41	40·7	38·93
22-11-37	2·25	2·46	24·0	1·33	40·7	38·23
29-11-37	2·25	2·51	25·9	1·32	40·0	38·50
6-12-37	2·27	2·53	24·1	1·32	40·3	39·13
13-12-37	2·23	2·43	23·4	1·26	41·0	38·80
20-12-37	2·08	2·19	23·4	1·23	31·7	33·97
27-12-37	2·04	2·10	20·4	1·18	18·3	32·20
3-1-38	2·06	2·13	22·3	1·07	16·3	34·33
Critical difference	±0·0939	±0·154	±2·301	±0·1032	±9·258	±2·919

*At a conference in December 1940, Mr. V. Venkataraman of the Indian Central Cotton Committee Technological Laboratory, Matunga, Bombay, suggested to one of us that a further application of analysis of variance to the values of fibre-characters of samples from the second, third and the fourth sowing dates in pickings up to 13 December 1937 may bring out any finer variation in lint quality within these pickings. This analysis was carried out and it was found that no finer variations, other than those brought out in the above analysis, were indicated.

The difference in fibre characters of samples picked before and after the middle of December are rendered more marked in Table IX where the average values of these characters are given in columns 2 and 3 respectively. It will be seen that the lint picked before the middle of December

TABLE IX

Fibre character	Average value	
	Up to 15 December 1937	After 15 December 1937
1	2	3
1. Mean fibre-length (cm.)	2·27	2·06
2. Modal length (cm.)	2·52	2·14
3. Fibre-length irregularity (per cent)	24·6	22·0
4. Mean fibre-weight per unit length (10^{-6} gm/cm.)	1·28	1·16
5. Percentage of mature fibres	35·6	21·1
6. Highest standard warp counts (calculated)	39·15	33·5

was, on the average, longer, heavier and maturer than that picked after that date. While the lint obtained from pickings before the middle of December could spin up to 39·0 (calculated) H. S. W. C., that from pickings after that date could spin only up to 33·5 (calculated) H. S. W. C. The quantity of lint yielded after the middle of December being only 5·74 per cent of the total, the advisability of not mixing the yield obtained after this date with that obtained before is too evident to need further emphasis.

The perfectly representative nature of the values of fibre characters of samples used in deriving the above conclusions regarding the variations in lint quality with progressive pickings was demonstrated by the significance of the residual correlation coefficients (r) between the pairs of fibre characters :

(*a*) Mean fibre-length and mean fibre-weight per unit length,

(*b*) Mean fibre-weight per unit length and percentage of mature fibres, and

(*c*) Percentage of mature fibres and mean fibre-length.

TABLE X

Correlation coefficients

Source of variation	D. F.	Correlation coefficients		
		r_{lw}	r_{wm}	r_{ml}
1	2	3	4	5
Sowing dates	2	+0·3606	+0·3426	−0·7526
Pickings	13	+0·7165	+0·8232	+0·5862
Residual	26	+0·0913	+0·6322**	+0·4438*

N.B.—l stands for mean fibre-length ; w stands for mean fibre-weight per unit length; and, m stands for percentage of mature fibres

*Significant at 5 per cent level

**Significant at 1 per cent level

The values of r are given in columns 3, 4 and 5 of Table X. The modal length and fibre-length irregularity are not included in this analysis as these, being characters derived by calculation from mean fibre-length, would show trends of variation quite similar to that of mean fibre-length. After separating the correlation coefficients due to sowing dates and to pickings, the residual correlation coefficient between the first pair of fibre characters was $r_{lw}=+0\cdot0913$ and that between the second pair $r_{wm}=+0\cdot6322$, and that between the last pair $r_{ml}=+0\cdot4438$. For 25 degrees of freedom the first correlation coefficient was non-significant, the second was significant at 1 per cent level and the last significant at 5 per cent level. This result is in conformity with that obtained by Koshal, Gulati and Ahmad [1940] from quite different considerations altogether.

SUMMARY

In a major portion of the Canal Colonies in the Punjab, the general agricultural practice of sowing cotton extends over a period of about a month from 15 May to 15 June. To study the effect of date of sowing on the quality of lint of P.-A. 289F/43, sowings were carried out in 1937 in randomized blocks with seven replications The dates of sowing were :

I. 15 April
II. 5 May
III. 20 May
IV. 4 June and
V. 1 July.

The third and the fourth sowings were within the range of general agricultural practice, the second was slightly earlier, the first too early and the fifth too late. The lint produced in each of the sowings was tested for the six fibre characters.

(*a*) Mean fibre-length,
(*b*) Modal length,
(*c*) Fibre-length irregularity (per cent),
(*d*) Mean fibre-weight per unit length,
(*e*) Percentage of mature fibrers, and
(*f*) Highest standard warp counts (calculated).

The third and the fourth sowings yielded lint of the same quality. The second sowing, somewhat earlier than in normal agricultural practice, had, in this year, produced lint of the same quality as in the third and the fourth sowings. The first sowing produced lint definitely inferior in quality to those from the second, third and the fourth sowings. The pickings from the fifth sowing were on the aggregate similar in quality to corresponding pickings from the second, third and the fourth sowings even though the lower percentage of mature fibres in the former would detract from the quality of the yarn spun from them by introducing such undesirable factors as neppiness, which are known to be caused, *inter alia*, by immature fibres.

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EFFECT OF DIFFERENTIAL IRRIGATION ON FIELD BEHAVIOUR AND QUALITY OF PUNJAB-AMERICAN 4F COTTON*

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THE Punjab has perhaps the biggest irrigation system in the world. Of the total cultivated area of about 30 million acres under all kinds of crops, about 50 per cent is irrigated from canals, wells, tanks and other sources of water supply. The canals, however, are the biggest source of irrigation, supplying water to more than 70 per cent of the irrigated area. The area under cotton has averaged about 2·8 million acres during the last five years, and of this about 93 per cent or 2·6 million acres is irrigated. About 65 per cent of the total area under cotton in the Punjab is concentrated in the Canal Colonies which comprise the richest districts in the province. Amongst the Canal Colonies, the Lower Chenab Canal Colony, with its headquarters at Lyallpur, is the oldest and most prosperous.

The authorized discharge of the Lower Chenab Canal is 9,900 cusecs in *rabi* (winter) and 11,000 cusecs in *kharif* (summer). The duty of water is 352 acres of which the permissible cultivation is 264 acres. This means that the canal authorities guarantee irrigation to 75 per cent of the cultivated area. The high level of prices of agricultural produce during the early twenties, coupled with a lack of proper appreciation of the water requirements of the various crops, induced the zemindars to sow areas much in excess of the permissible. The inevitable result was that, on account of a larger area under crops than was justifiable on the basis of water supply, all crops received less water with consequent reduction in yield. The canals are run on a very rigid system and while the canal authorities cannot allow a flow larger than the permissible either in the main or the subsidiary channels, the zemindars, having sown bigger areas, are always attempting to lay the blame of lower yields at the door of the canal authorities. This is especially the case with cotton. Experiments were, therefore, designed to find out the optimum water requirements of the Punjab-American cottons, using 4F as the standard, as this variety is the one which is most extensively cultivated.

PREVIOUS LITERATURE

Watering experiments on cotton have not been done on any extensive scale in India.

Milne [1922, 1924] remarked that the failures of cotton occasionally experienced in the Punjab were manifestation of water stress behaviour in abnormal years of low humidity and high temperatures during flowering and fruiting season. He recommended that American cotton should be given two irrigations in September, two in October and one in November or December. King [1922] carried out experiments on the irrigation requirements of Pima cotton in Arizona. He found that heavier yields were obtained with more frequent irrigation. Shantz and Pemeisal [1927] state that 574 ± 9 lb. of water were required by the cotton plant to produce one lb. of dry matter. This figure compared very favourably with that of wheat and oats in that locality. Beckett and Dunshee [1932] have reported their results on the water requirements of cotton on sandy loam soil in Southern San Joaquin valley of California. They found that 'When grown with available moisture continuously present throughout the season to 5 ft. depth, a full stand of cotton used on an average of 29·5 acre inches'. McDowell [1937] carried out irrigation experiments on Miller loam soil in Arizona using irrigation rates ranging from 2 to 34 acre inches. He found that the highest average yield of lint per acre resulted from the use of 30 acre inches of water.

Ramanatha Ayyar, Ahmad and Thirumalachari [1940] have reported the results of watering experiments on Cambodia cotton. They found that although highest yield was obtained by applying irrigation every week, but irrigation every three weeks was most profitable. They also found that ridging the soil did not result in any economy of water.

EXPERIMENTAL METHODS AND RESULTS

In ecological relation to the cotton plant, the climate of the Canal Colonies could be described as hot and dry during the period of sowing germination and early growth, i.e. during April,

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May and June. The period of active vegetative growth—July and August—coincides with the monsoon season when the climate is hot and moist. During both these periods hot winds are very common and there are usually 10-15 dust storms. The main flowering season (September-October) is mild and dry. The picking season, i.e. November, December and early January is usually dry and cold. There is, however, an expectation of light showers about Christmas time. The first frost usually occurs during the third week of December. There are no frosts after 15 February.

The experiment was designed according to the method of Udney Yule in which all treatments were arranged in a systematic order without randomization and there were 8 to 10 replications each year. The area of individual beds was 1/10 acre and non-experimental strips 9 ft. wide, accommodating three rows of cotton, were provided between the experimental beds to eliminate the effect of lateral seepage. The quantity of water applied to each bed at each irrigation was measured by means of Cipolletti weirs [Wadsworth, 1922].

The systems of irrigation under experiment were as follows :

Type I. Irrigation after every three weeks

Type II. Irrigation after every four weeks

Type III. Irrigation after every five weeks

For the first five years of the experiment, these three types of irrigation were applied to both flat beds and ridged plots according to the Egyptian method of sowing cotton which consisted of making ridges 2½ ft. apart, watering them and then dibbling seeds on ridges keeping 15 in. distance between consecutive holes. The uniformity in wetting of ridged and flat plots in consecutive irrigations was obtained by letting in each time a measured quantity of water by means of Cipolletti weirs.

Type IV. First irrigation was given at an interval of three weeks after sowing and subsequent irrigations after every fortnight.

Type V. (Started in 1930). First irrigation three weeks after sowing and subsequent irrigations as for Type VII.

Type VI. (Started in 1930). Irrigation as for Type VII with two or three late irrigations.

Type VII. Zemindari irrigation. Irrigations were given according to the method followed by cultivators. One cultivator in a nearby village was taken as the standard and irrigations to these beds were given on the dates when this cultivator irrigated his cotton. It may here be mentioned that holdings, in general, are not very large and several farmers are served by one channel. The normal interval between successive turns, to any one cultivator, is 12 or 13 days. There are sometimes canal closures which upset this routine. An average programme of irrigation followed by cultivators is as follows :

The first irrigation is given five to seven weeks after sowing, followed by three irrigations at

TABLE I

Irrigations and rainfall

Year		IF	IR	IIF	IIR	IIIF	IIIR	IV	V	VI	VII	Rainfall	Remarks
1928	N	7	7	5	5	5	5	10			6		The number of irrigations in II & III were equal due to interference by rain
	W	16·39	14·89	12·39	11·55	12·50	11·24	24·54			14·59	11·71	
	T	28·10	26·60	24·10	23·26	24·2	22·95	36·2			26·3		
1920	N	6	6	4	4	3	3	9			5		
	W	17·84	17·78	11·15	12·85	9·38	9·03	22·58			13·97	8·64	
	T	26·5	26·4	19·8	21·49	18·00	17·67	31·2			22·6		
1930	N	7	7	5	5	5	5	9	7	6	5		The number of irrigations in II and III were equal due to interference by rain
	W	16·58	18·81	13·11	14·03	12·43	13·86	21·78	16·33	13·96	11·36	5·43	
	T	22·0	24·2	18·5	19·5	17·9	19·3	27·2	21·8	19·4	16·8		
1931	N	6	6	4	4	3	3	7	4	6	5		
	W	17·95	17·88	11·84	11·76	8·97	9·03	20·84	11·08	17·79	15·15	15·73	
	T	33·7	33·6	27·6	27·5	24·7	24·8	36·6	27·4	33·5	30·9		
1932	N	7	7	5	5	4	4	10	7	8	6		
	W	20·07	19·89	24·29	14·22	12·00	12·06	29·25	20·06	23·11	17·15	6·72	
	T	26·8	26·6	21·0	20·9	18·7	18·8	36·0	26·8	29·8	23·9		
1933	N	6	...	4	...	4	...	9	4	5	3		
	W	18·03	...	11·96	...	11·96	...	26·97	12·13	14·89	8·98	13·05	
	T	31·1	...	25·0	...	25·0	...	40·0	25·2	27·9	22·0		
1934	N	6	...	5	...	4	...	9	7	8	6		
	W	17·99	...	15·03	...	12·09	...	26·92	20·94	23·95	17·83	5·48	
	T	23·5	...	20·5	...	17·6	...	32·4	26·4	29·4	23·3		
1935	N	7	...	5	...	4	...	10	7	8	6		
	W	21·00	...	15·07	...	11·85	...	30·02	21·02	24·00	17·98	3·57	
	T	24·7	...	18·7	...	15·4	...	33·6	24·6	27·6	21·5		

N — Number of irrigations
W — Acre inches of water applied through irrigation
T — Total acres inches of water applied (irrigation+rainfall)

F — Flat
R — Ridged

interval of three weeks. The last two irrigations are given at intervals of two weeks.

It must here be mentioned that wide deviations from the above routine are not possible as each cultivator has to distribute his share of water to all his crops.

The programme of irrigation as detailed above had to be modified during monsoon on account of the rain and suitable adjustments had to be made.

The details of irrigation are given in Table I.

Development records

Counts of flower production and boll maturation were kept in all years.

Flower production. Flower counting was done in all treatments every year. For this purpose six plants were chosen at random from each bed and the flowers produced per plant per day were counted. The number of plants chosen for this purpose in the different types of irrigation varied from 48 to 60 according to the number of repetitions in any one year.

The plants in heavily watered beds had a tendency to produce the first flower somewhat later than the plants receiving comparatively less water. King [1922], however, found that 'the plants frequently watered produced a greater number of flowers during the first 45 days of flowering'. He, therefore, found that frequent irrigations after the appearance of first flower were conducive to earlier crop.

The correlation between the amount of water applied and the number of flowers produced, between the number of flowers opened and the bolls produced and between the number of flowers and the final yield obtained have been worked out for different years and are given in Table II.

TABLE II

Correlation between watering, flowering, bolling and yield

Year	Watering and flowering	Flowering and bolling	Flowering and yield
1928	0·472	**0·900	0·305
1929	0·379	**0·844	0·089
1930	0·034	**0·832	0·422
1931	0·447	**0·842	*0·639
1932	—0·407	**0·817	0·379
1933	0·381	0·522	0·178
1934	0·239	**0·880	0·235
1935	0·492	**0·978	*0·846
Within years . .	0·239	**0·860	**0·355

**Significant at 1 per cent level
*Significant at 5 per cent level

It may be mentioned that in working out the correlations the number of flowers and bolls have been taken only from flat beds and the yield from the entire experimental plot.

It will be seen that the quantity of water applied had no effect on the number of flowers produced. The correlations in individual years as well as that within years were all non-significant. In 1932 the correlation was negative, although non-significant. This was probably due to unusually early occurrence of frost during this year.

The correlations between flowering and bolling were all significant except during 1933. No explanation can be suggested for this deviation.

The correlations between flowering and yield in the individual years were non-significant except during 1931 and 1935, when these were significant at 5 per cent level. If, however, the results of all the years are considered together, the correlation between number of flowers and yield is significant at 1 per cent level.

Boll production. Boll counting was also done on the plants reserved for flower counting. Due to daily handling these plants were somewhat stunted, but as the effect of handling was equal in all cases the figures obtained from various treatments are comparable.

A point worth mentioning is that as the plants supplied with less water had a tendency to produce flowers earlier than those supplied with more water, it was to be expected that boll production would also be earlier in the former case. This actually happend and the 'arrival' of the crop in the beds irrigated less frequently was earlier than in those having more irrigations. In this connection the statement made by King [1922] would be of interest. He says that 'plants growing in soil which was supplied with water sparingly throughout the season produced a greater number of bolls late in the season than plants provided with larger supplies of soil moisture'. It has, however, always been found at Lyallpur that larger supplies of soil moisture tended to make the crop late.

The correlations between the amount of water applied and the number of bolls produced and between the number of bolls and the yield obtained are given in Table III.

It will be observed from Table III that the correlation between bolling and watering was non-significant in individual years, but when all the years were considered together a significantly positive correlation at 5 per cent level was obtained. This indicates that in general the number of bolls per plant is likely to be improved by the application of greater quantity of water to the crop. This fact becomes very interesting when it is considered that a large

number of irrigations did not increase flowering (Table II), but it did improve bolling. It may, therefore, be concluded that the increased quantity of water somewhat reduced the shedding percentage of bolls.

TABLE III

Correlation between watering, bolling and yield

Year	Watering and bolls	Bolling and yield
1928	0·565	0·431
1929	0·416	0·212
1930	0·463	**0·804
1931	0·300	0·584
1932	—0·287	0·619
1933	—0·429	—0·681
1934	0·600	0·618
1935	0·645	**0·918
Within years	*0·298	**0·515

**Significant at 1 per cent level
*Significant at 5 per cent level

The correlation between bolling and yield was mostly non-significant in individual years, but when the results of all the years were considered together, the correlation was significant at 1 per cent level.

It must, however, be reiterated that both the flowering and bolling records were taken on the same plants which became stunted due to constant handling [Templeton, 1932] and therefore such plants were not exactly representative of other plants in the field. But since handling of the plants was done each year and in each treatment, the number of flowers and bolls produced under different irrigation treatments can be mployed for purposes of comparison.

Yield

The yield obtained from the various treatments in different years is given in Table IV.

As types I, II and III are comparable, it may be observed that ridge sowing versus flat sowing has given indifferent results. The difference was most marked in 1931 in which ridged plots gave distinctly lower yields than the flats. Although sowing on ridges is the universal method in Egypt, this practice has been found of doubtful value in the Punjab and the extra cost of ridging the soil and dibbling the seed by hand does not seem to be justified. As regards the flat beds, type I was significantly (5 per cent level) better than both types II and III in 1930. During 1928 and 1933, type I gave better results than type II, though the difference in yield was statistically significant only in the latter year. The difference in yield between type II and type III, however, was not significant in both these years. During 1929 and 1935, both types I and II, though equal in themselves, were significantly better than type III. During 1931, type I was significantly better than type III while the difference in the yield of type II and type III was not significant. The year 1932 was rather peculiar in that during this year type I irrigation, in which the greatest quantity of water was applied, gave the lowest yield. This was, probably, due to the occurrence of early frost in this season. The opening of bolls in beds which received this treatment was somewhat delayed

TABLE IV

Tabulated yields in lb. per acre of watering experiment

Types	1928	1929	1930	1931	1932	1933	1934	1935	Average 1928-35
I Flat	444	1029	1603	892	845	1581	1366	823	1072
I Ridge	465	1078	1522	778	916	..	..	..	952
II Flat	339	920	1044	885	1100	1339	1259	823	964
II Ridge	368	1000	1087	711	978	..	..	..	829
III Flat	382	709	1058	781	1031	1399	1128	445	867
III Ridge	371	799	1006	599	1027	..	..	..	760
IV Flat	751	1139	1624	919	1153	1491	1811	1210	1262
V	..	..	1339	875	1276	1358	1559	1112	1253
VI	..	..	1250	796	1043	1402	1497	976	1161
VII	451	921	1336	828	922	1389	1511	1005	1165
Standard error	±60	±67	±78	±36	±77	±77	±100	±93	
Critical Mean difference 5 %	141·900	158·455	176·436	81·432	174·174	188·419	244·700	227·571	
Critical Mean difference 1 %	209·940	234·433	253·500	117·00	250·250	285·439	370·700	344·751	

and frost did more damage to the crop in these beds as compared to the beds which had received less water and were, therefore, earlier in ripening.

On the average of eight years, it may be said that the crop which was irrigated after every three weeks gave heavier yield than the crop irrigated after longer intervals.

Type IV is a class by itself. Heaviest yield was usually recorded in this type.

Types V, VI and VII are again comparable. The differences in yield in these types were non-significant in all years except 1932 when type V was better than both types VI and VII. There was no difference between types VI and VII, showing thereby that no irrigation after the middle of October was required by the crop.

Statistical study by means of the analysis of variance and covariance of the amount of water applied and the yield obtained showed that the yield was, in general, correlated with the amount of water applied to the crop. The data are given in Table V.

TABLE V

Analysis of covariance

Year	D. F.	Sum of squares of yield	Sum of products	S. S. for water	Correlation
1928	7	120667·87	3879·28	128·84	**0·984
1929	7	143465·87	4303·22	157·12	**0·907
1930	9	505574·90	5147·16	90·36	*0·762
1931	9	85032·40	2025·28	157·16	0·580
1932	9	142304·90	1406·47	265·18	0·221
1933	6	43041·43	2017·96	215·45	0·663
1934	6	296307·70	6297·61	155·72	**0·927
1935	6	375465·70	7407·00	213·76	**0·827
Within years	59	1711860·77	32483·98	1383·59	**0·668

**Significant at 1 per cent level
*Significant at 5 per cent level

It will be seen from Table V that the coefficients of correlation between the amount of water applied and the yield obtained were non-significant during 1931, 1932 and 1933. A possible explanation for this is that the rainfall was very high during 1931 and 1933 (Table I) and the differential effect of the varying number of irrigations was masked. In 1932, on the other hand, the frosts occurred very early and the beds which had received larger quantities of water, being late in maturing, suffered more. This had an equalizing effect on the yields obtained from various beds and, therefore, the correlation coefficient between the amount of water applied and the yield obtained was non-significant. It may, however, be stated that, within the limits of the present experiment, high yields were usually obtained by applying larger quantities of water.

TECHNOLOGICAL TESTS

(*a*) *Fibre and spinning tests.* The samples of P.-A. 4F raised in the four seasons 1932-36 with different treatments of irrigation were tested at the Technological Laboratory for mean fibre-length, fibre-weight per inch and percentage of mature, half-mature and immature fibres. They were furthermore spun into suitable counts, and the yarns obtained were tested for lea breaking strength, single thread strength, yarn evenness and number of neps per yard. The methods employed in carrying out these tests as well as the number of tests made in each case have already been described by one of us [Ahmad, 1933]. The results of these tests have been summarized in Table VI.

We can draw a number of interesting conclusions by comparing among themselves the values given in Table VI of the various fibre properties of the samples or their spinning performance. However, as the same treatment was given to these samples for four successive seasons, we are in a position to apply the analysis of variance and covariance to the experimental data, which would give the correlation coefficients between the various characters as well as the critical differences by means of which we may judge the significance or non-significance of the observed differences. These calculations are shown in Table VII while Table VIII shows the mean values for the four seasons of each fibre property and the spinning performance together with the relative critical differences for $P = 0{\cdot}05$. Before we consider each property separately, we will offer a few general remarks on the extent and significance of variations observed in them. It will be noticed, from a comparison of the variance shown

TABLE

Fibre and spinning test results

Type of irrigation	No. of irrigations				Total amount of water received (in.) (Irrigation and rainfall)				Fibre-length (in.)				Fibre-weight per inch (10^{-6} oz.)			
	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36
I	7	1	6	7	26·8	31·1	23·5	24·7	0·76	0·76	0·84	0·79	0·160	0·158	0·137	0·151
II	5	4	5	5	21·0	25·0	20·5	18·7	0·77	0·74	0·80	0·80	0·156	0·142	0·148	0·156
III	4	4	4	4	18·7	25·0	17·6	15·4	0·77	0·73	0·76	0·76	0·143	0·139	0·153	0·156
IV	10	9	9	10	36·0	40·0	32·4	33·6	0·79	0·79	0·83	0·84	0·176	0·129	0·149	0·150
V	7	4	7	7	26·8	25·2	26·4	24·6	0·78	0·77	0·82	0·80	0·153	0·136	0·154	0·157
VI	8	5	8	8	29·8	27·9	29·4	27·6	0·78	0·76	0·81	0·83	0·148	0·144	0·153	0·128
VII	6	3	6	6	23·9	22·0	23·3	21·5	0·78	0·77	0·81	0·82	0·143	0·145	0·153	0·141

TABLE

Analysis of variance and covariance

Source of variation	Degrees of freedom	Sum of squares					
		Total amount of water received (in.)	Fibre Length (in.)	Fibre-weight 10^{-6} oz./in.	Maturity per cent	Standard hair wt. 10^{-6} oz./in.	H.S.W.C
1932-33	6	198·2771	0·000571	0·00080286	171·43	0·00071743	4·8571
1933-34	6	215·4543	0·002400	0·00048286	100·86	0·00052371	3·3571
1934-35	6	155·7143	0·004000	0·00023286	136·86	0·00035143	14·8571
1935-36	6	213·7543	0·004371	0·00066971	13·71	0·00099886	41·8571
Total (within seasons) . .	24	783·2000	0·011342	0·00218829	422·86	0·00259143	64·9284
Between 7 irrigation types . .	6	706·5886	0·007671	0·00023236	135·93	0·00031436	27·6250
Error . .	18	76·6114	0·003671	0·00195593	286·93	0·00227707	37·3034

VI

of P.-A. 4F. 1932-36

Maturity (per cent)				Standard hair-weight 10^{-6} oz.				Total loss (pe cent)				Neps per yard				Highest standard warp counts			
32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-38	33-34	34-35	35-36
44	61	33	46	0·194	0·170	0·168	0·174	17·7	16·8	19·4	18·4	0·9	0·6	0·7	0·9	24	23½	30½	26
41	53	34	47	0·192	0·162	0·181	0·178	16·1	16·9	18·7	18·4	0·7	0·9	1·2	1·1	23½	22½	29½	24½
49	49	35	47	0·169	0·164	0·189	0·180	16·2	17·0	19·1	18·6	0·9	1·6	1·4	1·0	24	24	29½	21½
52	60	44	47	0·202	0·141	0·173	0·174	15·2	16·5	19·1	18·0	1·0	1·6	0·6	0·6	25½	22	34	28
43	57	40	46	0·188	0·153	0·180	0·177	16·7	17·8	18·3	17·3	1·4	1·3	1·2	1·3	24½	23	32	29
36	57	42	49	0·191	0·158	0·176	0·143	17·5	16·6	18·4	17·2	1·1	0·8	0·4	0·9	26	23	31½	28½
41	56	32	44	0·178	0·162	0·188	0·165	17·8	17·8	18·9	17·2	1·1	0·6	0·7	1·2	25	22	31	27

VII

of P.-A. 4F. 1932-36

Sum of products					Correlation coefficient				
1·2	1·3	1·4	1·5	1·6	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}
0·21129	0·294457	33·8887	0·296186	22·7571	0·628	0·738	0·184	*·0785	0·733
0·42200	−0·098771	90·5714	−0·206914	−5·9214	0·587	−0·303	0·614	−0·616	−0·220
0·53200	−0·002471	121·0715	−0·137457	44·6714	0·674	−0·013	*0·829	−0·588	**0·929
0·78986	−0·138186	2·7143	−0·167429	74·8286	*0·817	−0·365	0·050	−0·362	*0·791
1·95515	0·055029	248·2429	−0·15614	136·3357	**0·656	0·042	*0·431	−0·151	*0·605
2·01093	0·053436	275·3036	0·238711	116·5000	*0·864	0·132	**0·888	−0·507	*0·834
−0·05578	0·001593	−27·0607	0·023097	19·8357	−0·105	0·004	−0·183	0·055	0·37

* Significant at 5 per cent level
* Significant at 1 per cent level

TABLE VIII

Fibre and spinning test results of P.-A. 4F. (mean values, 1932-36)

Type of irrigation	Mean for four seasons 1932-36					
	Amount of water received (in.)	Fibre length (in.)	Fibre weight per inch (10^{-6} oz.)	Mature hairs (per cent)	Standard hair weight (10^{-6} oz.)	H. S. W. Counts
I	26·52	0·788	0·152	46·0	0·1765	26·0
II	21·30	0·778	0·150	43·8	0·1783	25·0
III	19·18	0·755	0·148	45·0	0·1755	24·8
IV	35·50	0·812	0·151	50·5	0·1725	27·4
V	25·75	0·792	0·150	46·5	0·1745	27·1
VI	28·68	0·795	0·143	46·0	0·1670	27·2
VII	22·68	0·795	0·146	43·2	0·1733	26·2
Grand mean	25·66	0·788	0·149	45·9	0·1739	26·2
Critical difference for $P = ·05$		±0·021	±0·015	±5·93	±0·0167	±2·1

in the last two rows of Table VII that, except in the case of mean length, the variation was not significant even for 5 per cent level of significance for the other characters. This being the case, it follows that the variation produced by different amounts of irrigation in fibre weight per inch, maturity, standard hair weight or the spinning performance of this cotton was quite small. If as a result of further analysis we observe any positive correlation between the amount of irrigation and any of these properties, either for a single season or for the mean of four seasons, it should be taken to indicate only a trend which may be due to the operation of the variable irrigation factor or may be due to random causes.

We shall now consider each property separately.

(*b*) *Mean fibre length*. It will be seen from Table VII that only in one season, namely 1935-36, the correlation between the amount of water and the mean fibre length was significant, being non-significant, though positive in the other seasons. However, the correlation coefficient for all the seasons between the total amount of water applied and the mean fibre length of the cotton is positive and significant, showing that, in general, the application of more water during the growth period is likely to improve, to a very small extent, the mean fibre length of this cotton. This result is borne out by the mean values given in Table VIII, which show that the highest value is associated with the largest amount of water received by the crop, while it tends to decrease as less and less water is applied to it. This is especially the case for types I-IV. Apart from type IV, which entailing a large quantity of water, may not always prove a practical proposition, it will be noticed that type I gave, on the whole, significantly better results than type III, showing that irrigation after every three weeks might be conducive to the development of slightly longer fibres as compared with irrigtion after every five weeks. The difference between types II and III shows that from the point of view of staple length irrigation after every four weeks might be bettter than irrigation after every five weeks.

(*c*) *Fibre weight per inch*. The values of the correlation coefficients between the amount of water applied and the fibre weight per inch show that neither in any individual season nor for all the seasons taken together the amount of water had any significant effect upon the fibre weight per inch of this cotton. We may thus conclude that so far as the cultivation of this cotton under the conditions prevailing at Lyallpur is concerned the amount of water applied to the crop, within the limits of this experiment, did not produce any significant effect upon its fibre weight per inch.

(*d*) *Fibre maturity*. The correlation coefficient between the amount of water received by the crop and the percentage of mature hairs is positive in all the seasons, but only in one season, namely 1934-35, it is significant. If we take the results for all the seasons together, we find that the correlation coefficient between the percentage of mature hairs and the amount of water applied to the crop is positive and significant, showing that, in general, a tendency exists for this cotton to develop a higher percentage of mature fibres if more irrigation is given to the crop. This is also shown by the mean values given in Table VIII. It will be noticed that type IV, which represented the highest amount of irrigation, gave the largest

percentage of mature hairs, while among the other types, this percentage showed a tendency to decrease as less water was given to the crop. The difference between types IV and II is significant, while the other differences are non-significant. It will be further noticed that the zemindari types did not show any significant differences either among themselves or from the other types except type VII which gave significantly lower percentage of mature hairs as compared with type IV.

(*e*) *Standard hair weight*. Since the values of the fibre weight per inch and the percentages of mature, half-mature and immature fibres were available, the standard hair weight was calculated according to the following formula given by Peirce and Lord [1934], and statistical analysis was applied to it.

$$\text{Standard hair waight} = \frac{88.9\,W}{M + 0{\cdot}75\,H.M. + 0{\cdot}45\,I}$$

Where :

W = fibre weight per inch
M = mature hairs (per cent)
$H.M.$ = half mature hairs (per cent)
I = immature hairs (per cent)

The values of correlation coefficients given in Table VII show that with the exception of one season, namely 1932-33, the correlation coefficient between the amount of water applied and the standard hair weight is negative and non-significant. In 1932-33, however, this value is found to be positive and significant, which is rather unusual. On examining the individual values for this season, we notice an abnormally high value of fibre weight per inch for type IV. If this single value is omitted, the correlation coefficient ceases to be significant. It is therefore probable that this positive and significant correlation is due to this single value, although this point cannot be definitely decided on the basis of the present data. However, if we take the results for all the four seasons together, we find that, as in the case of fibre weight per inch, the correlation coefficient between the amount of water applied and the standard hair weight is non-significant, showing that the different irrigations tried in these experiments have no significant effect upon the standard hair weight of P.-A. 4F when grown under conditions normally prevailing at Lyallpur.

(*f*) *Neps per yard*. In view of the fact that neps are adjudged by the eye and that some of the small neps lying within the yarn may escape detection, a certain amount of subjective error is involved in the estimation of this yarn property. We have not, therefore, thought it necessary to apply the analysis of variance to it ; but, it will be noticed that, on the whole, the number of neps per yard is slightly higher for types III and V than for the other types and that among the latter the differences are quite small.

(*g*) *Highest standard warp counts*. It will be seen from Table VII that only in one season, namely 1933-34, the correlation between highest standard warp counts and amount of water was negative, while in the remaining three seasons, it was positive. Furthermore, if we take the results for all the seasons together, the correlation coefficient is positive and significant, showing that, in general, a tendency exists for this cotton to give better performance if more water is applied to the crop. This result is also brought out by the mean values given in Table VIII. It is interesting to note that two variations of the zemindari treatment compare quite favourably in respect of spinning performance with type IV, which represented the highest amount of irrigation, while the zemindari treatment compared quite favourably with type I in this respect.

Discussion

The results of eight years' watering experiment on Punjab-American 4F at the Cotton Research Farm, Risalewala, where the quantity of water applied at each irrigation was accurately measured, have been described. Certain features of these experiments are contrary to what has already been found elsewhere and it will be interesting to try to find out the causes of such discrepancies.

King [1922] has found in Arizona that heavily watered beds produced the majority of the flowers 'during the first 45 days of flowering' and that heavy irrigations were conducive to an earlier crop. Reverse was found to be the case at Lyallpur, as the heavily watered beds were later in maturity as compared to those where water was applied sparingly. King was experimenting with the Americo-Eygptian cotton Pima, whose habit of growth is different from the Punjab-American 4F. Moreover, the climatic conditions of Phoenix (Arizona) and Lyallpur are also vastly different as will be seen from Table IX.

Although it is recognized that the mean monthly normal temperatures are not to be relied upon in plant physiology studies, yet Table IX gives a bird's eye view of the differences in the climatic conditions of the two places. The weather at Lyallpur is much more severe during the growth and flowering season of cotton than the weather at Phoenix and the heavier and more frequent irrigations are helpful in keeping the plants in normal healthy condition at the former place. Shortage of water during this stage is likely to be far more disastrous at Lyallpur than at Phoenix. In Lyallpur the super-imposed condition of non-dehiscence of anthers [Trought,

TABLE IX

Mean monthly normal temperatures

	Phoenix, Arizona	Lyallpur	Giza, Egypt
January	51·2	53·3	51·6
February	55·1	57·6	54·1
March	60·7	68·8	59·4
April	67·0	78·7	66·2
May	75·0	87·9	72·7
June	84·5	93·9	77·7
July	89·8	92·1	79·9
August	88·5	89·0	79·4
September	82·7	85·9	75·0
October	70·6	77·3	70·9
November	59·7	64·9	63·1
December	52·0	55·6	54·9
Annual	69·7	75·4	67·1

1928] has also to be taken into account. Due to lack of pollination most of the flowers produced on all Punjab-American cottons till about the end of August each year are shed. Thus the effective flowering begins from the month of September. This condition does not exist in Phoenix where the early-formed flowers are most effective. Moreover, at Phoenix, most of the early-formed flowers, especially in beds receiving copious irrigations where shedding of bolls due to shortage of water is very slight, are matured into bolls with the result that the 'arrival' of the crop in such beds is earlier than in beds receiving less water.

Another instance is provided by ridged beds. As has already been said above, sowing on ridges is the universal method in Egypt, but this method has not proved useful at Lyallpur. The reason for this is not far to seek. The Egyptian soil is much heavier than the Lyallpur soil and germination is likely to be very defective on heavy soil without the aid of ridging. Mid-March is the optimum time of sowing near about Cairo. In upper Egypt sowings are now generally done in February. Sowing on the north side of ridges is universally practised. In Lyallpur, on the other hand, the sowings are usully done from 15 May to 15 June when the weather is very hot (Table IX) and ridged soil dries up within a few days. It is our experience that when sown on ridges the first three waterings should be given within the first month after sowing. If this is not done the 'stand' of the crop remains very poor and the yield proportionately reduced. Such huge quantities of water are not available in the Punjab and, therefore, sowing on ridges is not profitable. The Lyallpur soil is loamy and very friable and flat sowing usually results in excellent germination. In Egypt, cotton usually receives eight to eleven irrigations [Crowther, Tomforde and Mahmoud, 1937] as against five or six in Lyallpur. Frequent irrigations are absolutely necessary in the case of ridge sowing as will also be clear from Table IV. The average yield of ridged beds was 952, 829 and 760 lb. per acre in types I, II and III, respectively. Thus, by lengthening the interval between irrigation the effect on the yield was disastrous. The Punjab farmers cannot afford to apply frequent irrigations to their cotton crop and hence ridging is not a method which can be recommended to them. Balls and Holton [1915] have mentioned an interesting case wherein it is emphasized that large quantities of water should be applied at each irrigation to ridged plots in order to obtain the maximum yield. They have mentioned that instead of 'running water into groups of ten ridges at a time in the usual way and the closing them off to proceed to the next set of ten, we opened up 50 ridges at once, and turned the same flow of water into them. In this way a much greater quantity of water is given since the soil has time to absorb more of water'. In view of the general prevailing conditions in the Punjab, sowing on ridges may therefore be ruled out as an alternative to flat sowing.

We may now compare the results of technological tests with those found by earlier workers with other varieties of cotton. The earlier observations on the effects of irrigation on the fibre properties and the spinning performance of cotton are comparatively few. Mayton and others [1931] found, with reference to cottons grown in the Mississippi delta, that length of lint and size of boll were influenced by soil moisture, short lint being associated with low moisture content in the soil from 1 to 15 days after the appearance of the flowers. This observation agrees in general with our result that the lint length is positively correlated with the amount of irrigation applied to the crop. Sturkie [1934] made a detailed study of the influence of soil type, climatic conditions and soil moisture on the development of lint and seed in cotton. He found that, out of these factors, the amount of available moisture in the soil was the only one which influenced the development of lint in cotton. From his observations he concluded that low moisture content caused short lint to be formed, and that it was possible to reduce the length of lint by at least 1/8 in. by reducing the soil moisture to a critical point. This result also agrees, it will be noticed, with our observations on P.-A. 4F. This problem was attacked from a different angle by Koshal and Ahmad [1937]. They utilized the extensive data available for the standard Indian cottons and, applying to it Fisher's [1934] method of fitting the polynomials, evaluated the effect of rainfall sequence upon lint quality. They found that rainfall is an important weather-element,

which may account for $\frac{1}{2}$ to $\frac{1}{3}$ of the total variation in quality of cotton, that in the maturation period it is generally beneficial, while in the growing period it may be beneficial in the case of some cottons and harmful for others, and that even for the former cottons it is beneficial only in the first half of the growing period. These conclusions agree in a general way with the results of the present investigation ; but it is not possible to push the comparison further, partly because the statistical analysis was not applied to the Punjab cottons owing to the paucity of relevant data and partly because, in the present investigation, we are considering the effect of additional irrigation, which is not exactly equivalent to additional rainfall. The effect of differential irrigation on the field behaviour and quality of Cambodia Co 2 cotton has been studied by one of us in collaboration with Ramanatha Ayyar and Thirumalachari [1940]. Statistical analysis was not applied to the fibre-test results but it was noted that while the mode of irrigation did not affect the mean fibre length of this cotton, it influenced the fibre weight per inch, which showed a tendency to increase with the amount of water applied to the crop. The strength of the yarns was slightly less for the irrigated than for the unirrigated samples, and these small differences were attributed to the increase in fibre-weight per inch with irrigation. It will be noticed that the results for Cambodia Co 2 are in some respects different from those obtained for P.-A. 4F, which was found to improve slightly in length and spinning performance with the amount of irrigation. This differential behaviour is no doubt connected with the type and texture of the soils in the two areas and with the climatic conditions prevailing at the two places in the growing and maturation periods. It indicates the desirability of exercising caution in making general statements regarding the response of cottons to agronomical factors and the necessity of carrying out well-designed experiments in areas differing in respect of soil and climate.

Summary

The results of irrigation experiment on Punjab-American 4F involving seven different types of irrigation have been discussed. Flowers and bolls produced per plant were not correlated with the quantity of water given to the crop ; but, in general, the yield was correlated with watering. Ridging versus flat sowing gave indifferent results.

Application of more water during the growing period is likely to improve, to a small extent, the mean fibre length of P.-A. 4F. The amount of irrigation applied to the crop did not produce any significant effect either on the mean fibre weight per inch or the standard hair weight of this cotton. The percentage of mature hairs in P.-A. 4F showed a tendency to increase with the amount of water applied to the crop.

The spinning performance of this cotton showed a small tendency to improve as more water was given to the crop. It is noteworthy in this connection that the zemindari system of irrigation and its two variants compared favourably in respect of spinning performance of the lint with the type which represented the highest amount of irrigation.

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BASE-EXCHANGE STUDIES

II. VARIATION IN THE CONTENT OF EXCHANGEABLE BASES AFFECTING PLANT GROWTH

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(With Plate XV and three text-figures)

IN a previous communication, Singh and Nijhawan [1936] published the results of a preliminary investigation on the effect of different cations on the physico-chemical properties of the soil on the one hand, and their relationship to plant growth on the other. The study was primarily of a qualitative nature, and the influence of single bases saturating the soil's exchange complex was determined on wheat crop. The investigation though of fundamental importance did not furnish sufficient data which might solve the problem from the practical point of view, the reason being that these clays prepared in the laboratory did not represent true condition of soil in the field. For instance, a soil may contain calcium or sodium as a predominating exchangeable base, but it is not likely to meet under field conditions such extreme cases of soil which may behave in the same manner as calcium or sodium saturated soils prepared artificially. The same applies to soils saturated with other cations. Therefore, the present investigation was undertaken with a view to throw further light on this problem, and to study the effect of varying amounts of exchangeable bases under different conditions so as to bring into the scope of this investigation such types of soil as might occur under field conditions with respect to various cations.

The importance of exchangeable bases in the soil fertility has been fully realized, and a large amount of research work has been carried out during the past quarter of a century on the nature and properties which these bases confer on the soil's exchange complex by virtue of their presence in it, but little work of any importance has been done on the effect of these bases on plant growth. This is mainly due to the fact, that the preparation on a bulk scale of these clays containing varying amounts of exchangeable bases is not only an expensive but extremely laborious and tedious operation. The uptake of mineral salts by plants has been studied in great detail in water-culture solutions, but the conditions in soil, owing to its colloidal nature are entirely different, and the amount of salts that are rendered available to the plant under these conditions vary considerably. Therefore, it is of utmost importance to determine the amount of plant food material removed by the crop from soils containing varying amounts of exchangeable bases.

EXPERIMENTAL

Soil from the first foot stratum of an average field on the Lyallpur Agricultural Farm was obtained for the purpose of this investigation. The bulk sample, after being dried in the air, was powdered and sieved through a 2-mm. sieve. On analyses it gave the following results (Tables I—IV):

TABLE I

Mechanical analysis (per cent on air-dried soil)

Clay 0-0·002 mm.	Silt 0·002-0·02 mm.	Fine sand 0·02-0·2 mm.	Sand 0·2-2·0 mm.	Gravel above 2 mm.	Total carbonates ($CaCo_3$)
17·03	21·44	43·57	15·87	0·09	1·51

TABLE II

Analysis of HCl extract (per cent on air-dried soil)

Insoluble residue	Soluble silica	Iron (Fe_2O_3)	Aluminium (Al_2O_3)	Sodium (Na_2O)
82·56	0·11	5·00	4·36	0·21

Potassium (K_2O)	Calcium (CaO)	Magnesium (MgO)	Phosphorus (P_2O_5)
1·71	1·80	1·25	0·14

TABLE III

Analysis of citric acid extract, organic matter and total nitrogen (per cent on air-dried soil)

Potassium (K_2O)	Phosphorus (P_2O_5)	Organic matter	Total Nitrogen (N)
0·048	0·063	0·350	0·0308

TABLE IV

Exchangeable bases (milli-equivalents per cent)

Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Base exchange capacity
0·62	0·64	4·52	0·86	6·66

From the bulk sample, soils saturated with various cations were prepared by exhaustively leaching the soil with neutral chloride solutions of the respective cations [Singh and Nijhawan, 1936]. Sodium, potassium, calcium and magnesium soils thus obtained were thoroughly mixed with the original soil in the proportions given in Table V, so as to obtain soils containing varying amounts of exchangeable bases.

TABLE V

Plan of experiment

Soil series	Pot Nos.
A—Sodium group	
1. 100 per cent sodium clay	1—4
2. 75 per cent Na clay and 25 per cent soil .	5—8
3. 50 per cent Na clay and 50 per cent soil .	9—12
4. 25 per cent Na clay and 75 per cent soil .	13—16
B—Potassium group	
5. 100 per cent potassium clay . . .	17—20
6. 75 per cent K clay and 25 per cent soil .	21—24
7. 50 per cent K clay and 50 per cent soil .	25—28
8. 25 per cent K clay and 75 per cent soil .	29—32
C—Calcium group	
9. 100 per cent calcium clay	33—36
10. 75 per cent Ca clay and 25 per cent soil .	37—40
11. 50 per cent Ca clay and 50 per cent soil .	41—44
12. 25 per cent Ca clay and 75 per cent soil .	45—48
D—Magnesium group	
13. 100 per cent magnesium clay . .	49—52
14. 75 per cent Mg clay and 25 per cent soil	53—56
15. 50 per cent Mg clay and 50 per cent soil	57—60
16. 25 per cent Mg clay and 75 per cent soil	61—64
17. Original soil	65—68

350 gm. of the mixed soils thus prepared were filled according to the above plan in pots each measuring 11 cm. in diameter and 9 cm. in height, and fitted with a glass tubular near the bottom for aeration. In all 68 pots were prepared in this manner, which gave four repeats of each treatment. In order to guard against any deficiencies in the essential plant food materials, a mixture of potassium nitrate, ammonium nitrate and single superphosphate, containing 0·1315 gm. of nitrogen, 0·1315 gm. of potash and 0·0658 gm. of phosphoric acid was applied to each pot.

The pots were placed in a wire-gauze cage, and were given identical cultural treatments. After sowing with wheat they were sprayed with water from time to time in order to maintain the requisite amount of moisture in them. It was observed that only a small amount of water was absorbed by soils treated with sodium and potassium salts, and the bulk of it evaporated from the surface. To safeguard against desiccation, an additional quantity of water was added from time to time.

ANALYSIS OF THE SOILS

Exchangeable bases and pH values were determined in soils prepared for the pot experiments, and the results are depicted in Table VI. Exchangeable bases have been shown both as milli-equivalents per 100 gm. of the soil and as percentages of the total bases. A reference to this table shows that there is a regular gradation in the content of exchangeable bases placed under different groupings. When we consider the exchangeable base content of saturated soils only, we find that the displacement of bases does not take place completely, and it varies with the nature of the cations. The maximum displacement occurs in the case of calcium (98·04), and this is followed by sodium (94·14), magnesium (88·24) and potassium (86·09).

The pH values of these soils (Table VI) clearly indicate that the nature and the amount of cations in the exchange complex greatly affect the reaction of the soil. The soils containing monovalent cations have higher pH values than those having divalent cations. Further, the sodium group has a higher pH value than the potassium group in the monovalent series, and the magnesium group has higher value than the calcium group in the divalent series.

Differences in the pH values due to variation in the amount of exchangeable bases are depicted in Table VII.

It will be observed that a change in the amount of exchangeable sodium brings about a great variation in the pH values, as compared with a corresponding change in other groups. The variation is somewhat less in case of potassium, still less in magnesium and hardly any in calcium treated soils,

TABLE VI

Exchangeable bases and pH values

Soil series	Exchangeable bases *m. eq.* per 100 gm. of soil					Relative proportion of bases in *m. eq.* expressed as percentage of total bases				pH values
	Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Total	Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	
A—Sodium group										
1. 100 per cent sodium clay	6·200	..	0·310	0·075	6·585	94·14	..	4·71	0·14	9·99
2. 75 per cent Na clay and 25 per cent soil	4·866	0·161	1·420	0·267	6·714	72·47	2·40	21·15	3·98	9·68
3. 50 per cent Na clay and 50 per cent soil	3·520	0·330	2·420	0·478	6·748	52·24	4·90	35·92	7·09	9·14
4. 25 per cent Na clay and 75 per cent soil	2·007	0·502	3·480	0·681	6·670	30·09	7·53	52·17	10·19	7·97
B—Potassium group										
5. 100 per cent potassium clay	0·170	5·616	0·620	0·117	6·523	2·60	86·09	9·50	1·79	9·49
6. 75 per cent K clay and 25 per cent soil	0·272	4·397	1·520	0·321	6·510	4·17	67·56	23·35	4·93	8·92
7. 50 per cent K clay and 50 per cent soil	0·387	3·010	2·460	0·499	6·356	6·09	47·35	38·69	7·84	8·35
8. 25 per cent K clay and 75 per cent soil	0·492	1·860	3·340	0·686	6·378	7·71	29·17	52·37	10·75	7·82
C—Calcium group										
9. 100 per cent calcium clay	..	0·039	6·550	0·092	6·681	..	0·58	98·04	1·37	7·43
10. 75 per cent Ca clay and 25 per cent soil	0·153	0·199	6·000	0·285	6·637	2·30	3·00	90·38	4·29	7·44
11. 50 per cent Ca clay and 50 per cent soil	0·301	0·345	5·500	0·470	6·616	4·56	5·21	83·10	7·10	7·43
12. 25 per cent Ca clay and 75 per cent soil	0·459	0·416	5·020	0·669	6·564	6·99	6·33	76·48	10·19	7·43
D—Magnesium group										
13. 100 per cent magnesium clay	0·053	0·089	0·640	5·875	6·657	0·80	1·33	9·61	88·24	8·35
14. 75 per cent Mg clay and 25 per cent soil	0·196	0·263	1·520	4·603	6·582	2·98	4·00	23·09	69·94	8·14
15. 50 per cent Mg clay and 50 per cent soil	0·343	0·413	2·400	3·341	6·497	5·27	6·36	36·94	51·42	7·92
16. 25 per cent Mg clay and 75 per cent soil	0·482	0·519	3·420	2·104	6·525	7·38	7·96	52·42	32·24	7·71
17. 100 per cent original soil	0·622	0·642	4·520	0·861	6·645	9·36	9·67	68·03	12·95	7·43

TABLE VII

Differences in the pH values due to variation in the amount of exchangeable bases

pH range	Sodium group 7·43-9·99	Potassium group 7·43-9·49	Calcium group 7·43-7·44	Magnesium group 7·43-8·55
Differences amongst				
100 per cent and 75 per cent treated	0·31	0·57	—0·01	0·21
75 per cent and 50 per cent treated	0·54	0·57	0·01.	0·22
50 per cent and 25 per cent treated	1·17	0·53	0·00	0·21
25 per cent treated and original soil	0·54	0·39	0·00	0·28
Average pH difference	0·64	0·52	0·00	0·23

Analysis of citric acid extract

The analysis of the citric acid extract of the saturated soils (Table VIII) shows that the available potash is greatly reduced in the calcium and sodium saturated soils as compared with the original soil.

TABLE VIII

Analysis of citric acid extract of soils saturated with different cations

	Potassium (K_2O)	Phosphorus (P_2O_5)
Sodium-saturated soil	0·028	0·062
Potassium-saturated soil	0·314	0·060
Calcium-saturated soil	0·027	0·058
Magnesium-saturated soil	0·034	0·067
Original soil	0·048	0·063

These data lead to the following two conclusions: (*a*) That a large proportion of the citric-soluble potassium is formed by the exchangeable potassium ions that surround the clay particles; (*b*) The amount of available potash of the soils saturated with different cations is in the same order as their absorption capacities, viz. Ca>Na>Mg.

A reference to the data of available phosphoric acid shows that its amount is reduced in the case of calcium-saturated soil, while in the case of soils saturated with other cations it is almost equal to that present in the original soil.

PHYSIOLOGICAL CHARACTERISTICS OF WHEAT CROP

Wheat grains (8A) treated with hot water against loose smut were employed. Seeds of uniform size, weight and shape of kernal were selected, and soaked in distilled water for about 16 hours at room temperature. Five of these grains were sown in each pot in the first week of December at a uniform depth of one inch.

Germination

Germination started on the sixth day after sowing, and all the seeds germinated by the eighth day except in the case of 75 per cent sodium, 100 per cent and 75 per cent potassium pots where the number of days required for complete germination was nine. In 100 per cent sodium clay, however, germination started on the seventh day, and was complete by the eleventh day after sowing. Cent per cent germination was recorded in all the pots, but the adverse effect of sodium clay was noticeable by its retarding influence on germination.

Growth

A fortnight after sowing, only three plants of more or less uniform size were retained in each pot. Tillering was observed in the first week of January. The plants were healthy and strong in all the pots. They commenced to head out in the beginning of March and continued to flourish up to the time of harvesting, and yielded healthy and well-developed grains except in the sodium soils. In sodium-saturated soil, however, no seed formation occurred, and the crop was very poor. A somewhat similar conclusion was arrived at by Ratner [1935] who studied the effect of varying amounts of exchangeable sodium on plant growth.

Observations on the growth, height, and number of tillers per pot under different series were made, and the results are summarized in Table IX.

TABLE IX

Growth and yields of wheat crop

	Growth of wheat crop		Yield of wheat crop (gm.)		
	Average height of plants (in.)	Average No. of tillers per pot	Total yields	Straw	Grain
A—Sodium group					
1. 100 per cent sodium clay	6·68	7·75	3·90	3·90	..
2. 75 per cent Na clay and 25 per cent soil	7·84	13·50	5·80	5·00	0·80
3. 50 per cent Na clay and 50 per cent soil	9·00	12·75	6·80	5·38	1·42
4. 25 per cent Na clay and 75 per cent soil	8·88	26·25	7·22	5·57	1·65
B—Potassium group					
5. 100 per cent potassium clay	8·46	15·25	6·20	5·10	1·10
6. 75 per cent K clay and 25 per cent soil	9·89	22·75	6·90	5·65	1·25
7. 50 per cent K clay and 50 per cent soil	9·79	27·25	7·25	5·80	1·45
8. 25 per cent K clay and 75 per cent soil	9·20	26·75	7·55	6·30	1·25
C—Calcium group					
9. 100 per cent calcium clay	18·84	39·50	12·50	10·10	2·40
10. 75 per cent Ca clay and 25 per cent soil	14·96	36·00	10·62	8·25	2·37
11. 50 per cent Ca clay and 50 per cent soil	12·96	33·00	8·80	6·70	2·10
12. 25 per cent Ca clay and 75 per cent soil	10·29	25·75	7·80	5·90	1·90
D—Magnesium group					
13. 100 per cent magnesium clay	12·04	26·00	8·17	6·97	1·20
14. 75 per cent Mg clay and 25 per cent soil	11·92	28·25	7·80	6·75	1·05
15. 50 per cent Mg clay and 50 per cent soil	11·17	30·00	7·10	6·00	1·10
16. 25 per cent Mg clay and 75 per cent soil	11·29	27·00	6·54	5·44	1·10
17. 100 per cent original soil	10·96	29·25	7·70	5·90	1·80
Standard error	±0·285	±1·898	±0·161	±0·142	±0·064

Statistical examination of the data (Table X) shows that calcium and magnesium soils in high concentrations produced a very beneficial effect on heights, which in the former case was greater than in the latter. Lower concentrations (25 per cent calcium and 25 per cent magnesium), however, did not give any better results than the control, and the response to both these doses was not significant. Sodium and potassium, on the other hand, produced a harmful effect, and although in higher doses both were equally injurious to plant growth, in smaller doses the effect of sodium was more marked than that of potassium. As regards tillering, all the calcium-treated pots except 25 per cent calcium gave significant results, but none of the treatments in magnesium series proved to be effective. 25 per cent sodium, 25 per cent and 50 per cent potassium-treated pots behaved in the same manner as lower doses of magnesium, but 75 per cent sodium and 100 per cent potassium proved definitely injurious—100 per cent sodium produced the most deleterious effect.

The relative growth of wheat crop on different soils can also be observed from Plate XV.

Yields

The crop was harvested, and dried in the air. The grain and straw were weighed separately. A summary of the yield data is given in Table IX.

The statistical analyses of the total yields of wheat crop, the yields of grain and straw obtained from different soils have given the following results (Table X).

Calcium in higher doses significantly increased the yield of both total dry matter and the straw, while in lower doses (50 per cent and 25 per cent) and all doses of magnesium the differences were not significant. Taking the yield of grain separately, it was found that higher doses of calcium significantly promoted grain formation, while lower doses were without any effect. Magnesium, on the other hand, definitely and significantly reduced the yield of grain in all doses except 100 per cent magnesium where the results were not significant. Sodium and potassium bases in all doses unfavourably affected the yields of grain and straw. No significant differences were observed amongst sodium and potassium treated pots except that 25 per cent sodium yielded more of grain than 75 per cent sodium. 100 per cent sodium gave the minimum crop yield, but it was not significantly inferior to higher doses of potassium and the remaining doses of sodium in the case of yield of straw.

Analysis of crop and discussion of results

Analysis of plant material

The plant material from different soils after cleaning was dried in the sun and this was followed by drying in an electric oven (100-105° C.) for 24 hours. It was then incinerated over low flame and finally ignited in an electric muffle at a temperature not exceeding dull redness (550°C.) until the residue was almost white. The hydrochloric acid extract of the ash was prepared according to the official method of the A. O. A. C. and analyzed for sodium, potassium, calcium, magnesium and phosphoric acid.

The data of crop yields in terms of oven-dried material with its mineral composition are given in Table XI.

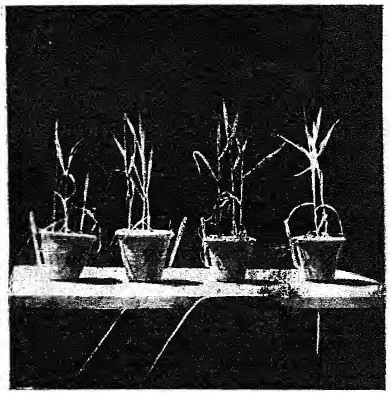
TABLE X

Analyses of variance of growth and yield data

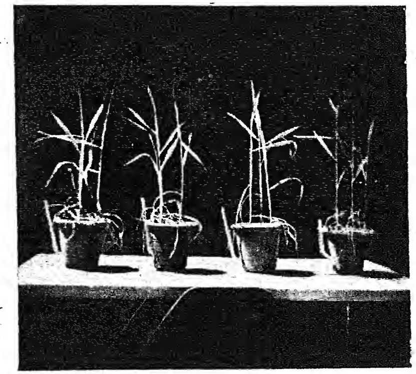
Source of variance	D. F.	Sum of squares	Mean square	Ratio of variance	Sum of squares	Mean square	Ratio of variance
		Heights of plants			No. of tillers per pot		
Between treatments	16	530·120	33·1325	102·040	3990·030	249·375	17·303
Within treatments	51	16·560	0·3247		735·500	14·412	
Total	67	546·680	..	..	4725·530	..	..
		Total yields			Yield of wheat straw		
Between treatments	16	14·340	0·8963	8·642	7·734	0·4834	5·961
Within treatments	51	5·290	0·1037		4·134	0·0811	
Total	67	19·630	..	..	11·868	..	..
		Yield of wheat grain					
Between treatments	15	1·427	0·0951	5·799			
Within treatments	48	0·786	0·0164				
Total	63	2·213	..	..			

The high values for the ratios of variances show that the effects of treatments in all cases are highly significant

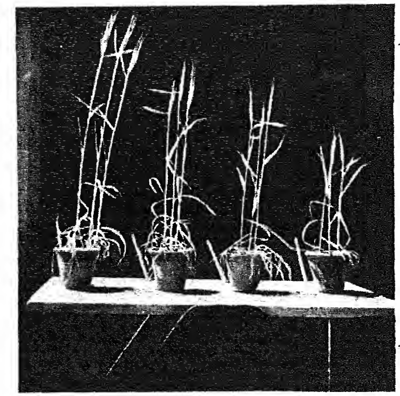
GROWTH OF WHEAT CROP AS INFLUENCED BY VARIATIONS IN THE CONTENT OF EXCHANGEABLE BASES



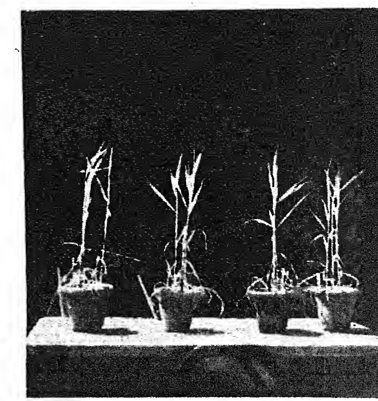
100% 75% 50% 25%
Sodium group



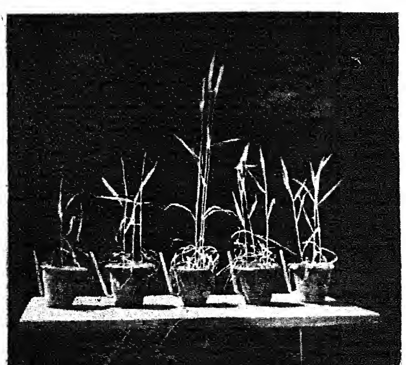
100% 75% 50% 25%
Potassium group



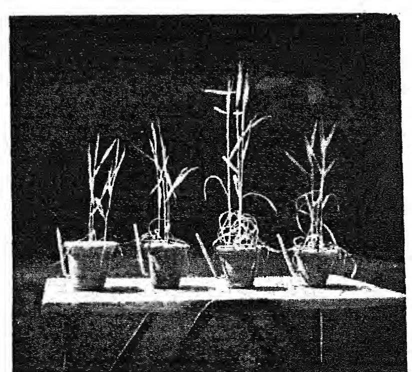
100% 75% 50% 25%
Calcium group



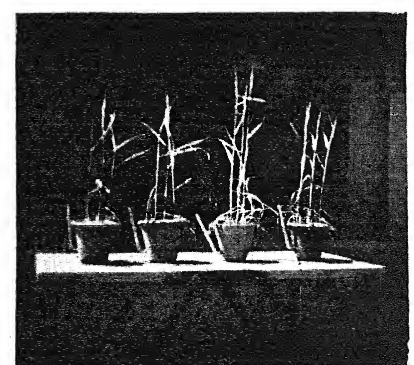
100% 75% 50% 25%
Magnesium group



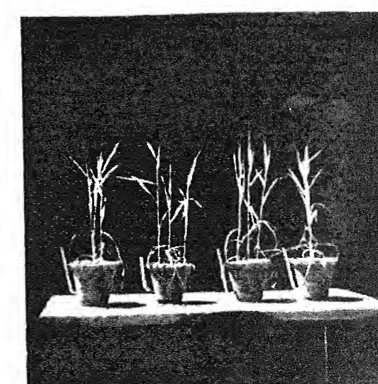
Na K Ca Mg Control
100% Clay



Na K Ca Mg
75% Clay & 25% Soil



Na K Ca Mg
50% Clay & 50% Soil



Na K Ca Mg
25% Clay & 75% Soil

Ash content of plants

It will be observed that the percentage ash content of plants grown on different soils varies considerably with the nature of cations (Fig. 1). The percentage of mineral matter removed by crops grown on soils containing divalent bases is less than that removed from the monovalent bases. Amongst the divalent bases the absorption from calcium soils is much less than that from the magnesium soils, while in the case of monovalent bases there is hardly any difference in absorption from sodium and potassium soils.

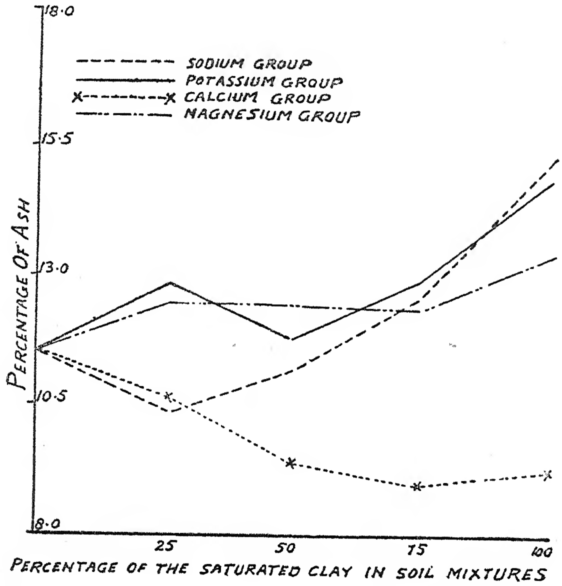


FIG. 1. Exchangeable bases and ash content of wheat crop

In the case of sodium, potassium and magnesium soils the percentage of mineral matter increases with the increasing amounts of their respective cations in the exchange complex, but reverse is the case with calcium soils, where percentage of mineral matter is least in calcium-saturated soil. In the case of saturated soils the order of mineral matter removed is K>Na>Mg>Ca.

When, however, the total quantity of mineral matter removed by the crop is taken into consideration, the order is changed, because the presence of the different bases not only affects the percentage composition of the crop, but the total dry matter is also affected to a much greater extent, with the result that the total mineral matter removed is maximum in that soil which gives the highest yield, and therefore the order is naturally in accordance with the yields of crops, i.e. Ca>Mg>K>Na.

TABLE XI

Yield and mineral composition of wheat crop

Soil series	Average oven-dried weight per pot (gm.)	Mineral composition (per cent on oven-dried material)						
		Ash	Insoluble residue	Sodium Na_2O	Potassium K_2O	Calcium CaO	Magnesium MgO	Phosphorus P_2O_5
A—Sodium group								
1. 100 per cent sodium clay	0·85	15·300	4·841	2·200	5·630	0·388	0·347	0·475
2. 75 per cent Na clay and 25 per cent soil	1·37	12·622	3·613	1·635	4·787	0·421	0·361	0·469
3. 50 per cent Na clay and 50 per cent soil	1·58	11·222	3·075	1·295	3·013	0·445	0·384	0·436
4. 25 per cent Na clay and 75 per cent soil	1·70	10·432	3·409	0·811	2·596	0·454	0·399	0·410
B—Potassium group								
5. 100 per cent potassium clay	1·38	14·699	3·432	0·241	6·658	0·296	0·293	0·556
6. 75 per cent K clay and 25 per cent soil	1·62	12·718	3·673	0·268	6·271	0·389	0·331	0·528
7. 50 per cent K clay and 50 per cent soil	1·72	11·792	3·515	0·349	5·470	0·443	0·381	0·516
8. 25 per cent K clay and 75 per cent soil	1·73	12·677	4·349	0·324	4·163	0·532	0·359	0·517
C—Calcium group								
9. 100 per cent calcium clay	2·76	9·336	2·658	0·350	1·969	1·840	0·377	0·291
10. 75 per cent Ca clay and 25 per cent soil	2·57	9·047	2·090	0·368	1·942	1·467	0·355	0·333
11. 50 per cent Ca clay and 50 per cent soil	2·09	9·441	2·569	0·471	2·794	1·060	0·400	0·369
12. 25 per cent Ca clay and 75 per cent soil	1·84	10·649	3·007	0·484	2·995	0·984	0·416	0·377
D—Magnesium group								
13. 100 per cent magnesium clay	1·57	13·420	4·357	0·840	4·593	0·464	1·095	0·827
14. 75 per cent Mg clay and 25 per cent soil	1·84	12·365	4·116	0·753	4·638	0·524	0·984	0·808
15. 50 per cent Mg clay and 50 per cent soil	1·63	12·408	4·494	0·619	4·162	0·653	0·798	0·789
16. 25 per cent Mg clay and 75 per cent soil	1·56	12·483	4·656	0·536	3·736	0·710	0·742	0·779
17. 100 per cent original soil	1·56	11·631	4·100	0·203	2·616	0·771	0·554	0·397

Availability of exchangeable bases to plant

From a study of the analytical data (Table XI) much information is gained regarding the influence of different cations in the exchange complex on the absorption of individual bases. The general trend of absorption is represented graphically in Fig. 2. The following salient points may, however, be noted :

1. The plants removed the largest amount only of those bases which predominate in the soil's exchange complex. This is in accordance with the findings of other workers [Singh and Nijhawan 1936].

2. The variation in sodium and potassium contents of crops removed from sodium and potassium soils respectively due to a change in the degree of saturation is greater than the variation in calcium and magnesium contents of the crop removed from the respective soils.

3. The dominant base in the exchange complex greatly affects the absorption of other bases by the plant. In sodium soils, an increase in the amounts

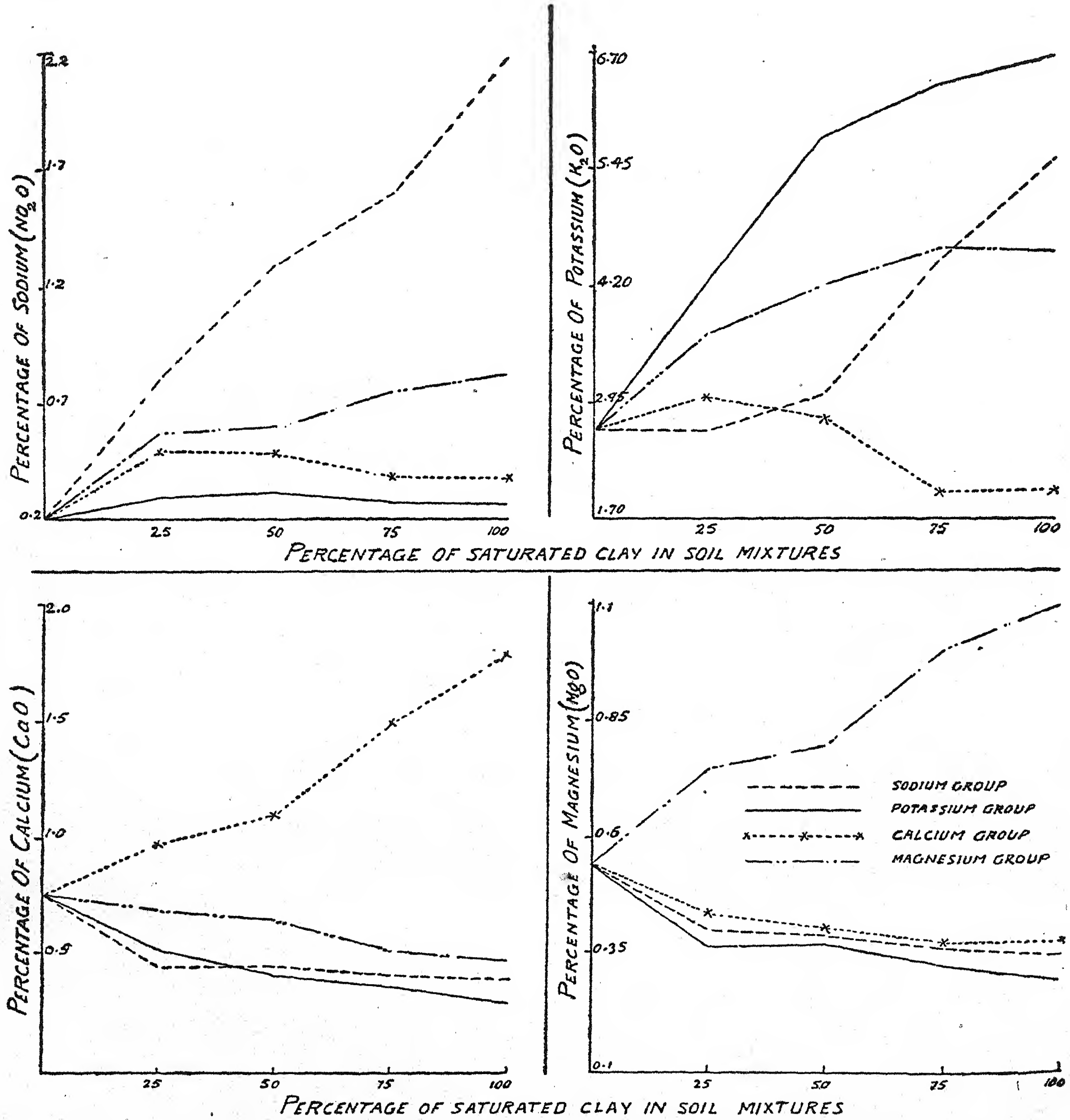


FIG. 2. Influence of exchangeable bases on the composition of wheat crop (sodium, potassium, calcium and magnesium)

of sodium increased the absorption of potassium but decreased the absorption of divalent bases, while in the case of potassium soils an increase of potassium ions not only suppressed the absorption of divalent bases but of sodium as well. Thus, it will be observed that whereas sodium ions promote the uptake of potassium, reverse is the case with potassium ions. Calcium soils showed a behaviour similar to those of potassium soils, with the only difference that the absorption of magnesium is not suppressed to the same extent as in the case of soils containing monovalent bases. Magnesium soils, on the other hand, behaved in an entirely different manner from other bases, as they increased the absorption of monovalent bases but suppressed the absorption of calcium.

4. The order of absorption of different bases from soils containing different cations is variable, e.g. calcium is absorbed in the largest proportion from calcium soils, and in the diminishing order from magnesium, potassium and sodium soils. These relationships are summarized below :—

Mineral constituent	Order of absorption from soils treated with different bases
CaO	Ca>Mg>K>Na
MgO	Mg>Ca>Na>K
Na_2O	Na>Mg>Ca>K
K_2O	K>Na>Mg>Ca

Availability of phosphorus

From the data presented in Table XI and Fig. 3 it will be observed that the nature of cations not only affects the absorption of different bases, but also produces a profound effect on the uptake of phosphoric acid.

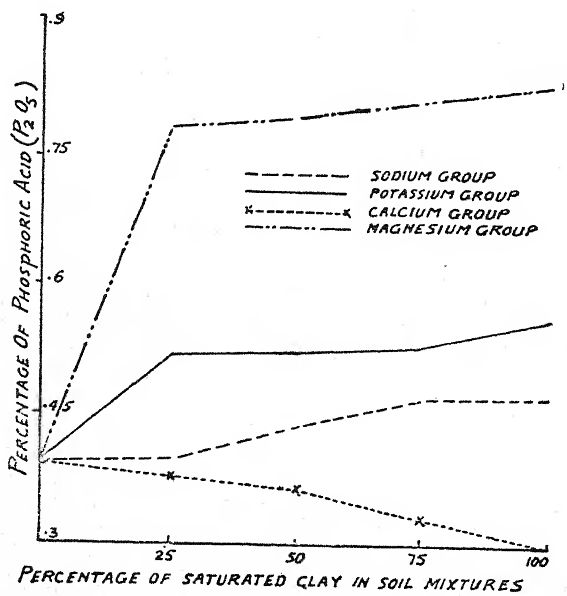


FIG. 3. Effect of exchangeable bases on the availability of phosphoric acid to wheat crop

The crop grown on magnesium soils contained the highest percentage of phosphoric acid, which increased from 0·78 to 0·83 per cent with an increase in the exchangeable magnesium. The next highest amount of phosphoric acid was removed from potassium soils, where the percentage varied from 0·52 to 0·56. The percentage of phosphoric acid removed from sodium soils was much less than that from magnesium or potassium soils, and was least in the case of calcium soils, the percentage varying from 0·29 to 0·38. In all cases with an increase in the exchangeable bases the amount of phosphoric acid removed by the crop increased, except in the case of calcium soils where an increase in the exchangeable calcium suppressed the absorption of phosphoric acid. Thus the order of absorption of phosphoric acid was Mg>K>Na>Ca.

General discussion

The crop yields from all the sodium and potassium treated pots are much below the control. At 75 per cent and 100 per cent levels they are found to be equally injurious to plant growth, but at lower levels (25 per cent and 50 per cent) potassium is not quite as harmful as sodium. Magnesium soils have given slightly better results than the control, but the calcium soils produce a marked beneficial effect on plant growth. The better growth of plants, as depicted by height measurements, the average number of tillers per pot, and the yield data, is due to an increased absorption of calcium by the plants, which is directly proportional to the amount of exchangeable calcium present in the soil. The plants grown on sodium, potassium, and magnesium soils remove decreasing amounts of calcium with increasing amounts of their respective cations, while reverse is the case when grown on calcium soils, i.e. the absorption of calcium is increased with an increase in the amount of exchangeable calcium. Thus, there exists a relationship between the exchangeable calcium of the soil and the plant growth, which increases significantly with an increase in the amount of exchangeable calcium [Gedroiz 1931].

The nature of cations absorbed by the soil also greatly affects the solubility of phosphorus. It is observed that the percentage of phosphoric acid increases in wheat crop to a maximum when grown in soils saturated with magnesium [Perkin, *et al.* 1932], while it is reduced to a minimum in soils saturated with calcium. The available analyses of the soils saturated with these cations also indicate the same fact, i.e. the amount of available phosphoric acid in calcium-saturated soils decreases, while that of magnesium soils increases. The increase of phosphoric acid in the crop grown on magnesium soils is probably due to the fact, as pointed out by Miller [1938], that magnesium acts

as a carrier of phosphorus. The salts of magnesium undergo dissociation very easily, and thus readily give up the anions which they carry.

The decrease in the percentage of phosphoric acid removed by the crop from calcium-saturated soil shows that phosphates are held up in the soil in a less readily available form. The fixation of phosphates may be due to the formation of calcium phosphate complexes, and the availability of phosphoric acid in calcium soils is one of the principal problems in the application of fertilizers to crops. Again, if they are held up in the soil in such a form as is unable to penetrate to the lower layers, it may be necessary to apply phosphatic manures in a form that is able to reach the root zone.

Similarly, the addition of calcium clay depresses the supplies of potash to the crop. It is surmised that this depressing effect may not be due to a decreased solubility induced by the addition of calcium clay, but due to a diminished supply of available soil potash caused by the replacement of potassium by calcium. This view is strengthened by the fact that the available potash content in calcium-saturated soil is less than that in the control.

The results obtained in the foregoing pages indicate that the exchangeable cations in the soil affect the availability of plant nutrients. Calcium bases increase the uptake of calcium by the plant, whereas sodium, potassium, and magnesium bases seem to depress its absorption. The maximum effect in this respect is produced at the point of saturation. Thus, the nature and amount of cations exercise an important influence on the fertility of the soil.

Summary and conclusions

The data presented in this investigation point out the important rôle played by the exchangeable bases on the growth and the composition of wheat crop. The study was carried out on an average soil from the Lyallpur Agricultural Farm.

The investigation involved the preparation of soils containing varying amounts of exchangeable bases. Data have been presented on the germination, growth, and yield of wheat crop grown on different soils. The amount of plant food material removed from these soils was determined by ash analyses of the crop.

The main conclusions arrived at as a result of these experiments may be summarized as follows :

1. The displacement of bases in the soil by any single base does not take place to the entire exclusion of the other. The degree of saturation varies with the nature of the cations and the order of displacement is Ca>Na>Mg>K.

2. (*a*) The nature of cations also affects the soil reaction considerably, sodium soils exhibiting the highest *p*H value, and the calcium soils the lowest. The order of soil reaction is Na>K>Mg>Ca.

(*b*) A change in the amount of exchangeable sodium brings about the greatest variation in the *p*H values of the soil, but a corresponding change in the calcium content produces only a small variation.

3. Germination is delayed in soils treated with monovalent bases.

4. Growth and yield of wheat crop is invariably better in soils treated with divalent bases than in those treated with monovalent bases. Calcium-saturated soils have given the best results, while sodium-saturated soils have proved to be most harmful. There is a progressive increase in yield as the amount of exchangeable calcium increases.

5. The percentage of mineral matter removed is the largest from potassium soils, and the least from calcium soils.

6. (*a*) Plants are observed to enjoy luxury consumption of the base which is in excess in the soil's exchange complex.

(*b*) The dominant base also greatly affects the absorption of other bases by the plant. Generally speaking, it suppresses the absorption of other bases, but sodium soils increase the absorption of potassium, and magnesium soils of both the monovalent bases.

(*c*) The order of absorption of different bases from soils containing different cations is variable.

7. The crop removes the maximum amount of phosphoric acid from magnesium soils, and the least from calcium soils. Increasing amounts of exchangeable calcium suppress the absorption of phosphorus by the plant.

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STUDIES ON THE DISTRIBUTION OF DIFFERENT FORMS OF PHOSPHORUS IN INDIAN SOILS

II. VERTICAL DISTRIBUTION

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In a previous paper the authors [Ghani and Aleem, 1943] have studied the distribution of phosphorus in the surface samples of a number of Indian soils collected from different localities and have discussed its importance with regard to the practical aspect of phosphate availability. In view of the interesting results obtained it was thought that a study of the vertical distribution of the phosphorus fractions in profile samples might give useful information. In the few attempts that have been made in the past attention has been confined mainly to the variation of the total phosphorus and dilute acid-soluble phosphorus with depth. There has been some speculation also as to the nature of phosphorus compounds that occur at different horizons of the soil profile [Heck, 1934; Pearson and others, 1940]. From the latter point of view, a fractionation study in the proposed manner would be of great value. With this object the profile samples from eight soils collected from different parts of India have been fractionated according to the procedure described by one of the authors [Ghani, 1942]. A brief description of the soils is given below.

Description of soils

No. 1. Dacca, Bengal

(*a*) 0—6 in. . Grey coloured loamy soil slightly dark due to organic matter. *p*H 5·2.

(*b*) 6 in. — 2 ft. 3 in. Yellowish grey heavy loam, sparsely mottled with iron. *p*H 5·3.

(*c*) 2 ft. 3 in. — 4 ft. Yellowish grey clay soil with numerous iron mottlings. *p*H 5·3.

No. 2. Bidar, Hyderabad (Deccan)

(*a*) 0—1 ft. . Brownish sandy soil mixed with 'murrams' of purplish gravel and of a few whitish nodular material. *p*H 6·2.

(*b*) 3—4 ft. . Decomposed trap mixed with a lot of whitish, yellowish material and a little soil. *p*H 6·4.

No. 3. Himayetsagar, Hyderabad (Deccan)

(*a*) 0—3 in. . Red sandy loam soil, parent material—granite. *p*H 6·4.

(*b*) 3 in.—1 ft. 6 in. Red sandy loam mixed with gravels. *p*H 6·4.

(*c*) 1 ft. 6 in.— 4 ft. Friable decomposed rock containing whitish material said to be due to decomposition of pigmatite. *p*H 7·3.

No. 4. Telankheri, Nagpur (C. P.)

(*a*) 0—2 in. . Red sandy loam mixed with boulders of partially decomposed basalt. *p*H 6·3.

(*b*) 2 in.—2 ft. 6 in. Red sandy loam mixed with larger boulders of partially decomposed basalt. *p*H 6·4.

(*c*) 13—16 ft. . Grey decomposed material. *p*H 6·7.

No. 5. Chandkheri, Raipur (C. P.)

(*a*) 0—4 in. . Light red loam soil mixed with iron concretions. *p*H 5·8.

(*b*) 4 in.—1 ft. 5 in. Red soil mixed with large amounts of iron concretions. *p*H 5·8.

No. 6. Buksa forest division, Rydak Forest (Assam)

(*a*) 0—9 in. . Light brown silt loam. *p*H 4·5.

(*b*) 9 in.—1 ft. 6 in. Slightly reddish loamy soil. *p*H 4·5.

(*c*) 1 ft. 6 in.— 2 ft. 3 in. Do. *p*H 4·4.

No. 7. Kurseong forest division, Sukna Reserve Forest (Bengal)

(*a*) 0—9 in. . Grey coloured silty loamy soil. *p*H 4·5.

(*b*) 9 in.—1 ft. 6 in. Slightly redish. *p*H 4·3.

(*c*) 1 ft. 6 in.— 2 ft. 3 in. Do. *p*H 4·1.

No. 8. Tenaserim (Burma)

(*a*) 0—6 in. . Dark loamy soil. *p*H 4·2.

(*b*) 6—12 in. Do. *p*H 4·2.

Discussion of results

The results of fractionation expressed both as mg. P_2O_5 per 100 gm. of soil and as per cent of the total P_2O_5 are given in Table I.

Total phosphorus

It will be seen from Table I that the total soil phosphorus is lower in the second depth (subsurface) of all the eight soils. In soil No. 4 there is a very slight increase though the rate of fall is different in different profiles. But the third depth

or subsoil samples in four out of five soils show an increase, in some cases considerable, over the subsurface samples, which goes to show that the total soil phosphorus is at a minimum at the subsurface layers. The evidences given by the previous workers are rather conflicting in this respect.

TABLE I

Vertical distribution of phosphorus fractions

Profiles	Acetic acid-sol.		Alk.-sol. inorg.		Organic		Sulphuric acid-sol.		Insoluble		Total
	A*	B†	A	B	A	B	A	B	A	B	A
1. Dacca, Bengal—											
0—6 in.	1·6	2	16·6	17	63·4	66	8·6	9	5·4	6	95·6
6 in.—2 ft. 3 in.	*Nil*	...	10·7	12	61·8	69	5·2	6	11·5	13	89·2
2 ft. 3 in.—4 ft.	Trace	...	10·0	15	41·2	62	6·0	10	8·8	13	66·0
2. Bidar, Hyderabad—											
0—1 ft.	700·0	50	229·3	16	26·7	2	63·8	5	382·0	27	1400·0
3—4 ft.	26·0	17	36·3	24	20·3	14	16·0	11	51·4	34	150·0
3. Himayetsagar, Hyderabad—											
0—3 in.	Trace	...	Trace	...	26·6	24	9·2	8	75·3	68	111·1
3 in.—1 ft. 6 in.	*Nil*	...	12·0	23	22·0	42	Trace	...	18·7	35	52·7
1 ft. 6 in.—4 ft.	43·0	28	21·3	14	10·7	7	28·0	18	51·0	33	154·0
4. Telankheri, Nagpur—											
0—2 in.	1·6	1	16·0	8	33·0	18	4·0	2	135·4	71	190·0
2 in.—2 ft. 6 in.	Trace	...	16·0	28	21·0	38	4·0	7	15·3	27	56·6
13—16 ft.	156·0	63	125	5	46·5	19	12·0	5	18·6	8	245·6
5. Chandkheri (C. P.)—											
0—4 in.	Trace	...	21·3	20	19·7	18	12·5	12	53·3	50	106·8
4 in.—1 ft. 5 in.	*Nil*	...	12·5	11	26·7	24	5·0	4	65·8	60	110·0
6. Buksa forest—											
0—9 in.	3·3	2	31·0	17	108·3	60	18·0	10	20·5	11	181·1
9 in.—1 ft. 6 in.	Trace	...	22·9	17	62·4	48	23·2	18	22·4	17	130·9
1 ft. 6 in.—2 ft. 3 in.	Trace	...	22·5	15	102·8	70	19·2	12	4·6	3	149·1
7. Kurseong forest—											
0—9 in.	Trace	...	28·8	14	88·5	42	19·6	9	73·8	35	210·7
9 in.—1 ft. 6 in.	Trace	...	26·6	17	96·0	62	22·4	15	9·6	6	154·6
1 ft. 6 in.—2 ft. 3 in.	Trace	...	26·1	17	80·5	51	18·0	12	31·0	20	155·6
8. Tenaserim—											
0—6 in.	6·1	3	26·0	13	59·3	31	14·0	7	88·6	46	194·0
6—12 in.	2·3	2	33·3	25	39·3	29	5·0	4	54·5	40	134·4

* A means mg. P_2O_5 per 100 gm. of soil † B means P_2O_5 in per cent of the total P_2O_5

Wheeting's [1924] results with five Michigan soils showed wide differences in the relative amounts of phosphorus found at four depths. In two of the soils highest percentage was found in the A-horizon, in two other in the B-horizon and in one soil in the C-horizon. Stephenson and Chapman [1931] found no correlation between the phosphorus content of various layers in eleven California soils. Walker and Brown [1936] analysed samples taken at 0-6⅔ in. and 20-40 in. and found that larger amount of phosphorus was present in the surface layers than in the lower zone.

Odynsky [1936] found that in four of the five Alberta soils, total phosphorus was at its minimum in the intermediate layers whereas in one soil it regularly decreased with depth. Pearson *et al.* [1940] in a study of 12 Iowa soil profiles found that in all cases the total phosphorus decreased with depth to a minimum between the lower A and the upper C horizons. Below this zone in 11 of the 12 soils, the amounts increased rapidly with depth to the bottom of the profile.

The results obtained here are similar to those obtained by Odynsky and Pearson. Pearson

suggested that the difference in the location of zones of maximum root development within the profiles may be responsible for variations in phosphorus distribution. That this is the case will appear from the vertical variation of the total phosphorus in the profiles of the two forest soils Buksa and Kurseong. In these two profiles, the differences in phosphorus content of the second and third depths are extremely small. Obviously this is due to an enlargement and downward shift of the zones of root development and phosphorus absorption, necessitated by the growth of forest trees. In the soils under ordinary crops and grass, the zone of maximum absorption is naturally located further up, as a result of which much phosphorus will be drawn from the subsurface layers impoverishing it by the process.

Acetic acid-soluble phosphorus

The acetic acid-soluble phosphorus is present only in traces in almost all the soils at all depths. Undoubtedly this is due to the acid nature of the soils. Only in the Bidar soil whose *p*H is above 6 and in the subsoil sample of Hemayetsagar whose *p*H is 7·3 the fraction occurs in a high proportion. Unfortunately these trace values of acetic acid-soluble phosphorus have made it impossible to detect the nature of change of the fraction down the profile. However, in many of the soils the surface samples contain some available phosphorus, though very small, while at the second depth it is practically absent. Soil No. 2 which is conspicuously rich in phosphorus contains 50 per cent of it in this form in the surface sample and the amount decreases to 17 per cent in a lower layer. This may probably indicate a downward decrease of the acetic acid-soluble fraction. In two of the soils (Nos. 3 and 4) 28 and 63 per cent respectively occur in the lowest layer though there is practically nothing in the upper layers. Though these results do not point to any definite conclusion yet they may add to the meagre stock of information that we possess on the subject.

Alway, McDole and Rost [1917] reported that citric acid-soluble phosphorus increased rapidly to a depth of 6 ft. and then remained constant in several soils developed from loess. Stephenson and Chapman [1931] found an increase in soluble phosphorus with depth in four of the eleven California soils. Lohsey and Runke [1933] reported an increase of soluble phosphorus with depth below the A_2-horizons of virgin podsolic and brown forest soils in Ontario. Odynsky [1936] found that phosphorus dissolved by $0{\cdot}002N$ sulphuric acid increased with depth throughout the profiles of three dark coloured unleached Alberta soils. Romine and Metzer [1939] using the same reagent found that soluble phosphorus was lower in the B than in the A horizons of six out of eight prairi soils. Pearson *et al.* [1940] showed that in nine out of twelve soils, dilute acid-soluble phosphorus increased in the lower A or upper B horizons. In seven of the soils the lower layers contained more than 25 per cent soluble phosphorus and in one soil 55 per cent as compared with 0·94 to 3·63 per cent found in the surface layers.

Alkali-soluble inorganic phosphorus

Table I shows that this fraction (iron and aluminium phosphates) decreases downwards in six out of the eight profiles. In two of the soils (Nos. 3 and 8) it shows a tendency to increase with depth. When the fractions are considered as per cent of the total phosphorus it is found that in six of the soils per cent iron and aluminium phosphates is higher in the second depth and then again it is lower in the third depth, showing that a maximum is attained in the intermediate layers. These are the same soils which showed a minimum of total phosphorus in the intermediate layers. It has already been pointed out that the intermediate layers may in all probability represent the zone of maximum absorption, at least in all arable and grassland soils. Accumulation of iron and aluminium phosphates keeping in harmony with the depletion of total phosphates in this layer may only mean that this form of phosphorus has not been removed by the plants to any appreciable extent. This gives an additional support to the prevailing view that iron and aluminium phosphates are comparatively unavailable to plants. A noticeable difference can again be observed in the behaviour of the two forest soils. In these cases also the fraction is at its maximum in the middle layer but the difference between the two lower layers is extremely small. This shows that accumulation of iron phosphates has progressed at the same rate in the two-layers, both being located within the zone of root development of the forest vegetation.

Sulphuric acid-soluble phosphorus

The phosphorus soluble in $2N$ sulphuric acid (apatites) is comparatively small and constitutes the single lowest fraction in the samples studied. The nature of changes with depth is practically the same as was observed with the alkali-soluble inorganic fraction. In the majority of the soils it reaches a maximum in the intermediate layers. As regards its availability, the same consideration will show that it is of little use to plants.

Insoluble phosphorus

The insoluble fraction varies with depth in a rather haphazard fashion. In three of the soils (Nos. 3, 4 and 8) per cent insoluble phosphorus regularly decreases whereas in the three others (Nos. 1, 2 and 5) it shows a regular increase. In one soil (No. 7) the intermediate layer contains the

lowest proportion, and another soil (No. 6) shows a maximum at the middle layer. Taking the absolute values of the fraction (mg. P_2O_5 per 100 gm. of soil) it is found that three of the soils show a minimum value and two a maximum value at the intermediate depth.

Organic phosphorus

In six of the soils the amount of organic phosphorus (per 100 gm. of soil) shows a decrease in the subsurface ; in two of them there is again a rise in the third depth. In one there is a slight tendency to increase downwards while in another a maximum amount is present in the middle layer. Again, when the fraction is expressed as per cent of the total soil phosphorus in most of the soils the highest percentage is present in the second depth. This shows as before an accumulation of organic phosphorus as a comparatively unavailable fraction in the intermediate layers in the profile. Auten [1922] found that in two of the three profiles he studied, organic phosphorus expressed as pounds per acre regularly increased up to the subsoil (third depth) while in one a minimum was reached at the subsurface layer. He further found that the ratio of total phosphorus to organic phosphorus was maximum in the middle layer in two of the soils and regularly increased in one.

For obvious reasons, the accumulation of organic phosphorus depends on many other soil factors besides the distance of the layer from the surface, as it is bound up with the occurrence of organic matter and its rate of decomposition.

It was, therefore, thought desirable to study the organic phosphorus in its relation to organic carbon and nitrogen and to examine the nature of variation of these constituents with their distance from the surface. Very little information is available at present on such relationships. Reference can only be made to the work of Auten [1922] who, in his study of the surface and subsurface samples of four Iowa soils, found the ratio of organic phosphorus to organic carbon to vary from 1/93 to 1/329 and the ratio of organic phosphorus to nitrogen to vary from 1/8 to 1/24.

C/N, C/P and N/P ratios

The carbon to nitrogen, carbon to organic phosphorus, and nitrogen to organic phosphorus ratios of the profile samples are presented in Table II.

It will be seen from Table II that organic carbon and nitrogen regularly decrease with depth in all the soils excepting No. 5. The organic phosphorus figures also indicate a similar behaviour. In soil No. 5 which shows a rise in the carbon content with depth, both nitrogen and organic phosphorus also exhibit a similar change. The downward decrease of the three constituents is not however in the same proportion, as will be evident from a comparison of the three ratios.

TABLE II

C/N, C/P and N/P ratios at different depths

Soil	Org. C per cent	Nitrogen per cent	Org. P per cent	C/N	C/P	N/P
1. *Dacca*—						
0—6 in. . .	1·260	·111	·028	11·3	45·0	3·9
6 in.—2 ft. 3 in. .	0·567	·067	·027	8·3	21·0	2·5
2 ft. 3 in.—4 ft. .	0·385	·048	·018	8·0	21·4	2·6
2. *Bidar*—						
0—1 ft. . .	0·772	·040	·012	19·3	64·3	3·3
3—4 ft. . .	0·349	·023	·009	15·1	38·8	2·6
3. *Hemayetsagar*—						
0—3 in. . .	0·607	·057	·012	10·6	50·6	4·7
3 in.—1 ft. 6 in. .	0·515	·055	·010	9·4	51·5	5·5
1 ft. 6 in.—4 ft. .	0·055	·008	·005	6·5	11·0	1·6
4. *Telankheri*—						
0—2 in. . .	1·471	·106	·014	13·9	105·0	7·5
2 in.—2 ft. 6 in. .	1·122	·089	·009	12·6	124·7	9·9
5. *Chandkheri*—						
0—4 in. . .	0·668	·047	·009	14·2	74·2	5·2
4 in.—1 ft. 5 in. .	0·956	·062	·010	15·4	95·6	6·2
6. *Buksa*—						
0—9 in. . .	3·192	·213	·047	15·0	67·9	4·5
9 in.—1 ft. 6 in. .	1·841	·116	·027	16·1	68·2	4·3
1 ft. 6 in.—2 ft. 3 in.	0·851	·085	·045	10·0	18·9	1·9
7. *Kurseong*—						
0—9 in. . . .	2·300	·194	·037	11·9	62·2	5·2
9 in.—1 ft. 6 in. .	1·590	·145	0·42	11·0	37·8	3·4
1 ft. 6 in.—2 ft. 3 in.	1·050	·106	0·35	9·8	30·0	3·0

The C/N ratio varies from 10·6 to 19·3 in the surface samples, the average value being 13·7. In the subsurface samples it varies from 8·3 to 16·1, the average value being 12·1. In the subsoil samples the ratio varies from 6·5 to 15·1 with an average at 9·9. The average ratio varies from 13·7 to 9·9 down the profile.

The C/P ratio varies from 45·0 to 105·0 in the surface, the average value being 67·0. In the subsurface it varies from 21·0 to 124·7 with an average at 66·5. In the subsoil samples, the ratio varies from 11·0 to 38·8, the average value being 24·0. The average ratio varies from 67·0 to 24·0 down the profile.

The N/P ratio varies from 3·3 to 7·5 in the surface with an average at 4·9. In the subsurface the ratio varies from 2·5 to 9·9, the average value being 5·3. At the subsoil layer it varies from 1·6 to 3·0 with an average of 2·3. The average ratio varies from 4·9 to 2·3 with depth with a maximum of 5·3 at the subsurface. The average variation of the three ratios at different depths are shown in Table III.

TABLE III

Average variation of C/N, C/P and N/P ratios with depth

Soil	C/N			C/P			N/P		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
Surface (7 samples)	10·6	19·3	13·7	45·0	105·0	67·0	3·3	7·5	4·9
Subsurface (6 samples)	8·3	16·1	12·1	21·0	124·7	66·5	2·5	9·9	5·3
Subsoil (5 samples)	6·5	15·1	9·9	11·0	38·8	24·0	1·6	3·0	2·3

The above results will further show that, as compared with organic carbon, both nitrogen and organic phosphorus breakdown at a lower rate in the lower horizons of the profile. This is revealed in a regular decrease of the C/N and C/P ratios down the profile. Again as compared with nitrogen, the rate of breakdown of organic phosphorus lessens with depth as is shown by the narrowing down of the N/P ratio. In Telankheri and Chandkheri soils the C/P and N/P ratios increase with depth. In the latter soil the higher carbon and nitrogen content at subsurface is mainly responsible for this increase. In so far as these findings will justify generalization it may be said that as the depth of the layer increases the rate of disappearance of these elements from the soil organic matter is of the order C>N>P or in other words, at lower depths the phosphatic organic matter is the most resistant of all.

It may also be readily observed from the above data that the correlation between organic carbon and organic phosphorus, and between nitrogen and organic phosphorus, would be fairly significant.

SUMMARY

A study has been made of the vertical distribution of various phosphorus fractions in a number of profiles.

The total soil phosphorus is at a minimum in the intermediate layers of the profiles, showing that phosphate absorption by plants is maximum in those layers.

The acetic acid-soluble phosphorus decreases with depth ; in some cases it is at its minimum at the middle layer.

Iron and aluminium phosphates expressed as percentage of the total phosphorus are usually at their maximum at the intermediate layers—the zones of maximum root development and phosphorus absorption showing that they are unavailable to plants. The apatite phosphate varies more or less in the same way.

Organic phosphorus, organic carbon and nitrogen decrease with depth in most of the soils. But expressed as per cent of the total phosphorus, organic phosphorus is present in the highest percentage in the second depth. On an average, C/N and C/P ratios decrease with depth whereas the N/P ratio shows a maximum in the subsurface.

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A PRELIMINARY STUDY OF RESPIRATION IN RELATION TO NITROGEN METABOLISM OF POTATO TUBERS

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(With two text-figures)

It has been known for a considerable time that the exposure of surface to air after injury is accompanied by enhanced oxygen absorption and carbon dioxide production. Associated with the increased respiration rate some observation on regeneration have been made by Steward, Wright and Berry [1932], with cut discs of potato. They noted the production of prominent cytoplasmic strands with renewed protoplasmic streaming, the increase in the size of the nucleus and occasional cell division in the surface cells exposed to air. They postulated that these cytoplasmic changes culminating in meristematic activity would involve transformation in the nitrogenous substances within the cells.

The chemical changes in response to these activities of regeneration have been observed to a limited degree. Thus Gruss [1907] noticed an accumulation of sugar and an increase in the oxidizing enzymes and in the diastatic activity of the cells around the wounded potato. It was observed by Hopkins [1927] that the sugar content of the wounded potato increased with the disappearance of starch from the surface cells. Fredrich [1908] noted in the cells bordering the cut surfaces of potato an increase in total nitrogen and acidity and a decrease in total carbohydrate but an increase in reducing sugars. Besides these changes in carbohydrate content some observations have been made by Zaleski [1901], Heitlenger [1901], Kovchoff [1902], and Smirnoff [1903] on the nitrogenous substances of the wounded surface. The observations of all these investigators show that as a result of wounding an increase in protein nitrogen occurs, but no scheme has been suggested as to the way the soluble nitrogen passes into insoluble form. It was agreed by Smirnoff and Zaleski that in absence of air or in hydrogen these changes do not take place.

In the past a considerable amount of work has been done to advance the knowledge of protein synthesis in plants and in these investigations various plant organs have been employed to furnish evidence for the course of nitrogen metabolism. Amongst these the storage organs have not been adequately studied. Gruntuch [1929] noted that though the potato tubers have a low total nitrogen, yet they have also a very high soluble nitrogen. An observation on the transformation of such a high percentage of soluble nitrogen into protein nitrogen as a result of increased metabolic activities may add to our knowledge of protein synthesis in plants. The advantage of using cut discs of potato tuber exposed to air for such observations are as follows :

(1) In storage organs carbohydrate supply is adequate, which, besides being a source of energy for the synthetic cells, provides for the necessary carbon compounds of the protein molecule.

(2) The elimination of translocation prevents the loss or supply of any organic nitrogen to and from any other part of the organism so that the disappearance or production in excess of any particular nitrogenous compound may be directly accounted for the nitrogen metabolism of the organ.

(3) The observation is limited to a small bulk of uniform cells thus avoiding any complications due to complex tissue system.

(4) Storage tissue has been extensively used for salt absorption, the ability of which has been shown by Steward [1931] to be dependent on the physiologically active cells. In addition to the increased respiration rate the activities of the surface cells to regeneration have been mentioned before. The importance of salt absorption in these physiologically active cells concomittant with growth is obvious. From this it might be anticipated that the absorption of inorganic nitrogen by these cells may throw further light as to the way protein is normally synthesized in plants from inorganic nitrogen.

The experimental attack of the problem resolves itself into two main features to which simultaneous attention has been paid: firstly to the maintenance of proper conditions for allowing the cells to respire aerobically for a considerable time in an atmosphere free from carbon dioxide accumulation ; secondly the prevalence of ideal condition for salt absorption and water supply to the evaporating cells without interfering with aeration and carbon dioxide measurement during the course of the experiment.

Apparatus

The apparatus for the present investigation consists of two main parts (Figs. 1 and 2) ;

(1) The respiration chamber (R).

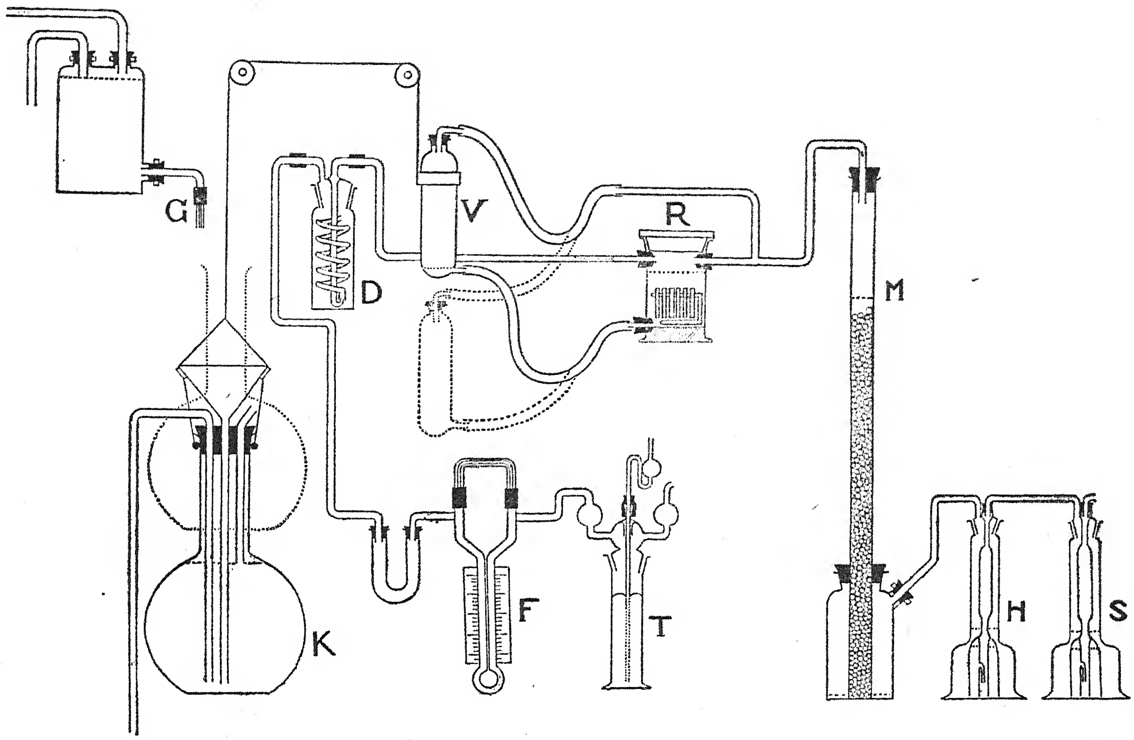

Fig. 1. Respiration apparatus

(2) The vessels (V), containing a liquid with accessory arrangements for the periodical flooding of the discs.

(1) *Respiration chamber* (R). This is a cylindrical jar with a ground glass stopper and provided with two holes just below the open end and one at the bottom. One of the upper holes serves as the inlet of carbon dioxide free air and the other at the opposite side allows the air stream containing respired carbon dioxide to be conveyed to the absorption bubblers (D). The hole at the bottom serves as an entry of culture solution to flood the discs. Six such jars are arranged in a parallel series in one plane. For aeration air free from any laboratory gas is drawn from outside the laboratory buildings by the suction of a filter pump. The air stream passes first through wash bottles (S, H) containing 20 per cent sulphuric acid and 40 per cent sodium hydroxide to remove atmospheric impurities and carbon dioxide. Finally the air stream before entering the respiration chamber is passed through a tower (M) packed with beads and containing 40 per cent sodium hydroxide to remove the last traces of carbon dioxide in the air. The carbon dioxide free air thus drawn enters the six respiration chambers through a combination of two (T) pieces; one arm of the (T) piece is connected to the vessels in order to equalize the pressure between the vessels and the respiration chambers and the other arm joins three respiration chambers. Similarly with second (T) piece air is delivered into the other three chambers. Then the air stream containing the respired carbon dioxide is led into the spiral bubbler (D) containing sodium hydroxide for the absorption of carbon dioxide. Air from each of the spiral bubblers passes into a six-way glass tube, then through a capillary flow meter (F), protected by calcium chloride tube, and Mariotte bottle, T, is finally removed by the suction of the water pump.

(2) *The vessels* (V). The main principle of this part of the apparatus is to flood the discs periodically with a liquid at desired intervals, while in the intervening periods the discs are allowed to respire in air. The vessel for holding the liquid is made of pyrex glass and is provided with two openings, the one at the bottom for conveying the liquid is drawn to a tube which connects with the lower hole of the respiration chamber through elastic rubber tubing. Six such vessels corresponding to the six respiration chambers (Fig. 2) are clamped to a metal stand. Two pieces of string from the two ends of the metal stand passing over pulleys are fastened on the opposite sides of the neck of a flask (K) acting an intermittent siphon, in such a way that the movement of the pulleys allows the flask to rise and fall vertically. The flask is provided with a well-fitted stopper with three holes,

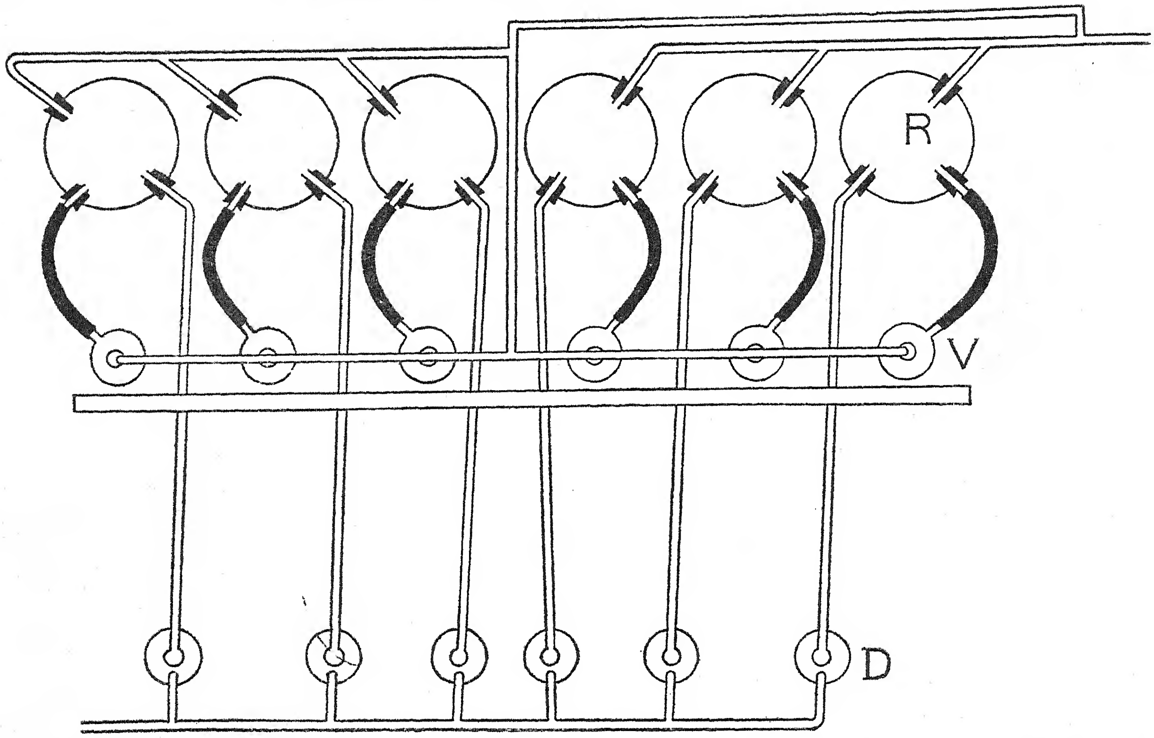

FIG. 2. Respiration apparatus showing the arrangement of respiration chambers (R), nutrient vessels (V), and alkali bubblers (D)

through one of the holes a siphon tube empties the water from the flask, the second is used for filling the flask through a funnel and the third hole allows inlet and outlet of air from the flask. The automatic movement of the flask is achieved by the working of the pulley system and the siphon tube. When the water level inside the flask rises to a certain height, the weight of the flask, becoming heavier than the combined weight of the metal stand and the vessels, lowers the former. By lowering of the flask the vessels are raised to a higher level and the discs are flooded with the liquid. The flask empties when the water level rises further to an adjustable height at which the siphon operates. The flask becoming lighter rises and the vessels fall by gravity and the discs are returned to air and the liquid flows back to the vessels. By the adjustment of the flow of water through a capillary (G) into the flask and the flow of the siphon tube, the interval for allowing the discs to respire in air and immersion in liquid alternately is maintained.

Experimental procedure

Cylinders of potato tuber (Var. King Edward VII) were cut symmetrically by means of a cork borer 3·2 cm. in diameter. These were then marked around with a string at distances of 3 mm. and cut into discs by a sharp scalpel. Discs having irregular thickness were discarded and those of approximately 3 mm. thickness were used. Six discs of 3 mm. thickness having a fresh weight of about 12 gm. could be conveniently arranged in each respiration chamber. For the complete analysis of all nitrogen fractions about 12 gm. of the fresh weight of the disc are necessary. Such discs, having a thickness of 3 mm. approximately, were used in all the experiments except in Experiment IV, where thicker discs were used. The discs of tissue were left in running tap water for 30 minutes to wash the starch grains from the cut cells. They were then superficially dried between filter paper, using a weighted photographic roller to ensure uniform drying and then weighed. All results are calculated in terms of this initial fresh weight. The control discs were also treated in a similar way and analysed immediately. Before the experiment is started, the apparatus is sterilized with formalin solution and thoroughly washed with distilled water. The discs are suspended vertically on a thin glass as shown in Fig. 1 and uniform spacing is kept between the adjacent discs. 75 c.c. of culture solution is used in each of the vessels for flooding the discs. The air stream is drawn for an hour to remove the last trace of carbon dioxide from the apparatus before beginning the experiment. A clean dry bubbler containing sodium hydroxide is then

connected to the respiration chamber to collect the respired carbon dioxide. Along with the change of the bubbler at the end of each period, fresh culture solution is used in the vessel. In order to remove any trace of carbon dioxide that may be held in the liquid, the liquid after each period is gently boiled while a stream of carbon dioxide free air is drawn through, and any carbon dioxide liberated is absorbed in alkali in the spiral bubblers. The liquid after each period of the experiment is preserved under sterile conditions to analyse whether any nitrogen has passed out of the disc into the liquid. The analysis of the liquid after evaporating down to a smaller bulk has shown that less than 1 per cent of nitrogen from the disc is lost in the culture solution in the vessels. The flow of air through the apparatus is maintained at five litres per hour, and care is taken to see that the air stream passes through the spiral bubblers at a uniform rate. The time during which the discs are allowed to respire in air was maintained at 9 minutes and 30 seconds. The discs were immersed in the solution for 1 minute and 30 seconds. With this arrangement the apparatus was very successfully run for a long period. At the end of the experiment the discs are found to be quite turgid and showed superficial browning similar to that noted by Steward [1931]. Immediately after the experiment the discs are dried superficially between the filter paper and their weights recorded. The discs are then divided into two portions: from one portion all soluble nitrogen fractions are analysed, and the other portion is dried at 100°C. for estimating total nitrogen. From the discs estimations of total nitrogen, total soluble nitrogen, protein nitrogen, total amino and amide nitrogen and residual nitrogen were made, according to the methods followed by Richards and Templeman [1936].

Estimation of carbon dioxide. The amount of carbon dioxide in the alkali in the bubbler is determined by noting the change in the conductivity of the alkali as described by Newton [1935]. The conductivity readings were taken by Dr R. Sankaran, to whom my thanks are due. The respiration rates are expressed as mg. of carbon dioxide per hour per gm. fresh weight of the disc.

Experimental results

Nitrogen metabolism

Preliminary experiments were performed to test the changes in the nitrogen metabolism occurring in the exposed disc under aerobic and anaerobic conditions at different temperatures. The production of carbon dioxide was not measured in these two experiments.

Experiment I. Six discs of 3 mm. thickness selected at random were used in each series. The control analysis was made immediately after sampling. The discs for aerobic respiration were kept for seven days in a Petri dish lined with moist filter paper; the loss of water from the discs was prevented by keeping the chamber moist. For anaerobic respiration the air from the intercellular spaces of the disc was exhausted by injecting water free from any dissolved gases. Then the discs were kept in a close chamber from which air was exhausted, the inside of the chamber was lined with moist filter paper. Both the series of the discs were kept at the laboratory temperature varying from 13° to 20°C. After seven days the discs were analysed for nitrogen fractions and the results are presented in Table I as percentage of fresh weight of the disc and in Table II as percentage of total nitrogen.

It is seen that the total nitrogen of potato tuber as percentage of fresh weight (Table I) is very low;

TABLE I

Nitrogen as percentage of fresh weight

—	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control fresh wt. 11·29 gm.	0·2590	0·2044	0·0546	0·0926	0·0429	0·0497	0·0621
Aerobic respiration fresh wt. 9·53 gm.	0·2590	0·1470	0·1120	0·0530	0·0194	0·0336	0·0604
Anaerobic respiration fresh wt. 10·13 gm.	0·2786	0·2100	0·0686	0·0966	0·0518	0·0448	0·0686

TABLE II

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control	78·92	21·08	35·75	16·56	19·19	23·98
Aerobic respiration . .	56·76	43·24	20·46	7·49	12·97	23·32
Changes from the control .	—22·16	+22·16	—15·29	—9·07	—6·22	—0·66
Anaerobic respiration . .	75·38	24·62	34·67	18·59	16·08	24·62
Changes from the control .	—3·54	+3·54	—1·08	+2·03	—3·11	+0·64

of this about 79 per cent in the control is soluble nitrogen, the total amino, amide and residual nitrogen are high. Regarding the amide nitrogen the assumption is made that all amides in the plant exist in the form of asparagine. On this assumption the absolute values of amino-acids are estimated from the difference between the total amino and amide figures [Sircar and Sen 1941]. On this basis it is observed that the tuber contains more amides than amino-acids as the control analysis shows here.

After seven days aerobic and anaerobic respiration the discs were found to be quite turgid. In the case of aerobic respiration superficial browning of the discs as noted by Steward [1931] was seen, but under anaerobic condition no such change in colour is observed. As a result of aerobic respiration for seven days at the temperature varying between 13° to 20°C. a considerable amount of protein is synthesized (Tables I and II).

It is evident that the increase in protein nitrogen is accompanied by a decrease in amino-acid and amide nitrogen, while the residual nitrogen remains at about the same level as in the initial analysis. It is noted that under aerobic condition there is more decrease from the control value in amino-acids than in amides. Under anaerobic condition the synthesis of protein is small. Together with the small increase in protein nitrogen the amino-acid nitrogen has also increased while the amide nitrogen alone has disappeared to the extent to which the protein is formed.

Experiment II. The second experiment was performed in a way similar to Experiment I, the temperature in this case was maintained constant at 25°C. The results of the nitrogen analysis are entered in Tables III and IV.

TABLE III

Nitrogen as percentage of fresh weight

—	Total N	Total cryst N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control fresh wt. 11·26 gm.	0·2422	0·1176	0·1246	0·0419	0·0055	0·0364	0·0393
Aerobic respiration fresh wt. 12·03 gm.	0·2422	0·1414	0·1008	0·0501	0·0165	0·0336	0·0577
Anaerobic respiration fresh wt. 11·99 gm.	0·2184	0·1092	0·1092	0·0644	0·0358	0·0266	0·0182

TABLE IV

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control	48 ·55	51 ·45	17 ·30	2 ·27	15 ·03	16 ·22
Aerobic respiration . .	58 ·38	41 ·62	20 ·69	6 ·82	23 ·87	23 ·82
Changes from the control .	+9 ·83	—9 ·83	+3 ·39	+4 ·55	—1 ·16	+7 ·60
Anaerobic respiration . .	50 ·00	50 ·00	29 ·49	17 ·31	12 ·68	8 ·33
Changes from the control .	+1 ·45	—1 ·45	+12 ·19	+15 ·04	—2 ·35	—7 ·89

The sample in this experiment was collected from a different batch of potatoes, but the total nitrogen is about the same as in Experiment I. Of this more than 50 per cent is in the form of protein nitrogen as seen in the control analysis. It is interesting to note that corresponding to high protein nitrogen there is only 2 per cent amino-acid nitrogen whereas the amide nitrogen is maintained high. The nitrogen metabolism has resulted in the breakdown of protein after seven days of aerobic respiration at a temperature maintained constant at 25°C. The degradation of protein has resulted in the increase in amino-acids and residual nitrogen, the increase is considerably greater in amino-acids than in any other fractions under aerobic condition. The amide nitrogen is reduced to a small extent.

At the end of seven days anaerobic respiration at this temperature, the discs became soft and some of the nitrogenous substances have diffused out of the cells, consequently the total nitrogen estimated as percentage of fresh weight is low. Of the total nitrogen that was estimated in these discs equal amounts of protein and soluble nitrogen are noticed (Tables III and IV). The amino-acid has increased considerably, the amide and the residual nitrogen have decreased.

Carbon dioxide production

Experiment III. For the third experiment the apparatus as described before has been used. The discs of average 3 mm. thickness are allowed to respire in the respiration chambers and are periodically flooded with water. The experiment is started with two series, one of short period and the other of longer period. A control analysis of nitrogen fractions was made immediately after sampling. The results of nitrogen analysis are entered in Table V as percentage of fresh weight and in Table VI as percentage of total nitrogen. The total amounts of carbon dioxide produced per gm. fresh weight are also given in Table VI. It is to be noted that the respiration measurements in the present investigation were made at long intervals to estimate the total amounts of carbon dioxide produced during the changes in the nitrogenous compounds of the exposed disc. From the data presented here it is not possible to show the respiration time curve,

TABLE V

Nitrogen as percentage of fresh weight

—	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control fresh wt. 13 ·04 gm.	0 ·2212	0 ·1648	0 ·0564	0 ·0771	0 ·0428	0 ·0343	0 ·0534
Short period 65 hours fresh wt. 13 ·62 gm.	0 ·2436	0 ·1428	0 ·1008	0 ·0684	0 ·0376	0 ·0308	0 ·0436
Long period 138 hours fresh wt. 12 ·97 gm.	0 ·2184	0 ·1056	0 ·1128	0 ·0473	0 ·0235	0 ·0238	0 ·0345

TABLE VI

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N	Total CO_2 mg. produced per gm. fresh wt.
Control . . .	74·50	25·50	34·86	19·35	15·51	24·13	..
Short period . .	58·62	41·38	28·08	15·44	12·64	17·90	4·375
Changes from the control	—15·88	+15·88	—6·78	—3·91	—2·87	—6·23	..
Long period . .	48·35	51·65	21·66	10·76	10·90	15·79	..
Changes from the control	—26·15	+26·15	—13·20	—8·59	—4·61	—8·34	10·701

the precise elucidation of which would necessitate a much modified technique so as to give frequent readings over small time intervals under controlled temperature conditions. At the end of short period considerable changes in the nitrogen content of the discs have occurred. There is a net gain in protein in both the periods, larger amount being synthesized at the end of long period. It is noticed that as between amino-acids and amides there is always more decrease in the former.

Surface-volume effects in nitrogen metabolism

Experiment IV. The surface : volume effects in respiration have been studied by Steward, Wright and Berry [1932] in detail. With discs of variable dimensions they have shown that the respiration of potato discs in air or immersed in liquid is not uniform throughout their mass, but the cells at the external surface in contact with free oxygen, either dissolved in water or present in a gaseous phase, contribute relatively much more carbon dioxide to the total than those in the interior. By using a wide range of thickness variation from 0·3 mm. to 19·7 mm. a quantitative measurement of the zone of high respiration and the inactive zone of tissue respiring at a normal rate has been made by Steward [1932].

In view of the surface-volume effects in respiration, the present experiment is made to observe the effect of thickness variation on the nitrogen metabolism. It may be mentioned that in the present experiment no attempt has been made to differentiate between the amount of carbon dioxide produced from the zone of high respiration and from the inactive zone and thus to correlate the increased carbon dioxide production with the changes in the nitrogenous compounds ; the precise computation of which would necessitate the use of discs thinner than those used here, namely 5 and 10 mm.

Duplicate series of 5 and 10 mm. thickness discs are allowed to respire in the respiration chamber, periodical supply of water to the evaporating cells is maintained as mentioned before. The temperature recorded in the thermograph varied between 13° to 21° C. The respiration rates are presented in Tables X and the nitrogen analysis of the discs are given in Table VII and VIII. Each series is provided with its own control analysis.

TABLE VII

Nitrogen as percentage of fresh weight

—	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
5 mm. thick control fresh wt. 25·30	0·2087	0·1407	0·0680	0·0736	0·0437	0·0399	0·0272
A fresh wt. 25·56 .	0·2068	0·1287	0·0781	0·0651	0·0356	0·0295	0·0341
10 mm. thick control fresh wt. 25·22	0·2188	0·1621	0·0567	0·0753	0·0350	0·0403	0·0465
B fresh wt. 23·49 .	0·2198	0·1583	0·0615	0·0737	0·0316	0·0421	0·0425

TABLE VIII

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
5 mm. thick control	67·42	32·58	35·27	16·15	19·12	13·03
A	62·23	37·73	31·48	17·22	14·26	16·49
10 mm. thick control	74·09	25·91	34·41	15·99	18·42	15·22
B	71·97	28·03	33·53	14·36	19·15	19·29

The changes in nitrogen content as noticed between 5 and 10 mm. thickness are compared with those of 3 mm. thickness of Experiment III (long period), which was performed under the same experimental condition and the results of comparison are presented in Table IX.

TABLE IX

Changes in percentage of nitrogen content from the control values

—	Protein N	Amino-acid N	Amide N	Residual N
3 mm. thick Sp. surface 8·84 cm².	+26·15	—7·59	—4·61	—8·34
5 mm. thick Sp. surface 5·08 cm².	+5·15	+1·07	—4·86	+3·46
10 mm. thick Sp. surface 3·21 cm².	+2·12	—1·61	+0·73	+4·07

It is evident that the variation in the disc thickness between 3 and 5 mm. has resulted in a considerable difference in the nitrogen metabolism (Table IX). With 3 mm. there is a considerable increase in protein nitrogen accompanied by decrease in amino-acid, amide and residual nitrogen, while using 5 mm. thickness less increase in protein nitrogen with a reduction of amide and an increase in residual and amino-acid nitrogen is obtained. A still smaller increase in protein nitrogen is seen with discs of 10 mm. thickness. From the data presented in Table IX it is noticed that the change in the nitrogenous compound is more intense with 3 mm. thickness than with 5 mm., whose surface exposed to air per unit weight of tissue as referred specific surface in Table IX, is greater than that of 5 mm. thickness. Similarly between 5 and 10 mm. thickness small increase in protein nitrogen is associated with a small change in the specific surface.

The mean respiration rate of the discs showing such variation in the nitrogen changes are presented in Table X.

TABLE X

Variation in disc thickness and mean respiration rate

Thickness of the disc in mm.	Specific surface cm.²	Mean respiration rate mg. CO_2 per gm. fresh wt.
3	8·84	0·0668
5	5·08	0·0438
10	3·21	0·0382

It is noticed that the mean respiration rates between 3 and 5 mm. thickness differs considerably and also the nitrogen changes are great. By increasing the thickness from 5 to 10 mm. the respiration rate is low, the increase in protein nitrogen is small. When the mean respiration rates are considered in relation to the surface of the disc exposed per unit weight of the tissue (specific surface per gm. of tissue), it is found that the rates are related to the change in the specific surface as has been shown by Steward.

Effect of feeding ammonium nitrate

Experiment V. In view of the absorption of ammonium nitrate by the storage tissue and its possible utilization in the nitrogen metabolism of the discs, in this experiment the discs are supplied with ammonium nitrate. The experiment is started with six series, three are supplied with ammonium nitrate and three with distilled water, as in the previous experiment. Potatoes of the same variety grown in the following season are used soon after they are harvested. The concentration of ammonium nitrate used is 2·38 gm. per litre. Temperature variation during the length of the experiment

is from 21° to 30°C. Of the six series, two with water and two with ammonium nitrate are run for six days and the remaining two for nine days. Each series is provided with its own control analysis and in order to minimize the errors due to sampling the discs from the tubers are so selected that each individual disc in the series has its own control from the adjacent region of the tuber. Nitrogen analyses of the six series are presented in Table XI as percentage of fresh weight and the respiration rates are entered in Table XV. Absorption of ammonium nitrate in the discs of treatment A, B and C is considerable and of this a greater amount is retained in the form of crystalloid nitrogen. It is noticed that the nitrogen supply to the discs has considerably increased all the nitrogen fractions with the exception of residual nitrogen in series A and C, which show a reduction. The statistical analysis (Table XIV) shows that this difference in A and C is not significant against the standard error. These changes are presented in Table XII as the percentage difference of nitrogen content from the respective control values.

TABLE XI

Nitrogen as percentage of fresh weight

Treatment	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
A. Control— Fresh wt. 16·16 gm.	0·2430	0·1707	0·0723	0·0890	0·0518	0·0372	0·0445
Ammon. nit. 6 days fresh wt. 14·23 gm.	0·3489	0·2702	0·0787	0·1584	0·0812	0·0772	0·0346
Changes from the control . . .	+0·1059	+0·0995	+0·0064	+0·0694	+0·0294	+0·0400	—0·0099
B. Control— Fresh wt. 14·30 gm.	0·2552	0·1745	0·0807	0·0923	0·0474	0·0449	0·0373
Ammon. nit. 6 days fresh wt. 14·19 gm.	0·4351	0·3355	0·0996	0·1740	0·0807	0·0933	0·0682
Changes from the control . . .	+0·1799	+0·1610	+0·0189	+0·0817	+0·0333	+0·0484	+0·0309
C. Control— Fresh wt. 14·40 gm.	0·2510	0·1676	0·0834	0·0877	0·0473	0·0404	0·0395
Ammon. nit. 9 days fresh wt. 13·34 gm.	0·4992	0·3706	0·1286	0·1936	0·0542	0·1394	0·0376
Changes from the control . . .	+0·2482	+0·2030	+0·0452	+0·1059	+0·0069	+0·0990	—0·0019
D. Control— Fresh wt. 14·55 gm.	0·2521	0·1789	0·0732	0·0951	0·0574	0·0377	0·0461
Water 9 days fresh wt. 14·60 gm. .	0·2549	0·1554	0·0995	0·0649	0·0275	0·0374	0·0531
E. Control— Fresh wt. 15·57 gm.	0·2485	0·1674	0·0809	0·0913	0·0592	0·0339	0·0423
Water 6 days fresh wt. 14·50 gm. .	0·2485	0·1533	0·0952	0·0730	0·0342	0·0388	0·0415
F. Control— Fresh wt. 14·92 gm.	0·2642	0·1765	0·0877	0·0930	0·0557	0·0373	0·0462
Water 6 days fresh wt. 14·40 gm. .	0·2537	0·1545	0·0992	0·0670	0·0297	0·0373	0·0502

TABLE XII

Difference in percentage of nitrogen content from the control values

Treatment	Total N	Total cryst. N	Protein N	Amino-acid N	Amide N	Residual N
Ammon. nitrate— 6 days A	+43·58	+58·29	+8·85	+56·76	+107·53	—22·25
6 days B	+69·71	+92·26	+23·42	+70·25	+107·80	+82·84
Ammon. nitrate— 9 days C	+98·88	+121·12	+54·20	+14·59	+254·04	—4·81

The synthesis of protein as a result of nitrogen supply is noteworthy. In both A and B after six days there is an increase in protein nitrogen, the increase is more in B which has absorbed more nitrogen. It is clear that feeding with ammonium nitrate has greatly increased the amino-acid content of the discs in A and B. The amide nitrogen figures presented here show a considerable increase, but it should be remembered that it also includes the free ammonia that has been absorbed by the discs and remains unmetabolized. In B a very high increase in the residual nitrogen is noticed which is also statistically significant (Table XIV), and this is possibly due to nitrate nitrogen. A comparison between A and B (Table XII) shows the same percentage increase in amide nitrogen (which estimates free ammonia) after nitrogen supply, while the percentage increase differs in total crystalloid nitrogen, B has absorbed more nitrogen. This increase in B from A in total crystalloid nitrogen is not as free ammonia as otherwise a similar increase would be expected in the residual nitrogen as nitrate nitrogen. After nine days the discs (C) have absorbed still more nitrogen and the synthesis of protein is also further increased. Of the total nitrogen absorbed a considerable portion is in soluble form. The increase in amino-acid nitrogen is maintained, but the increase is much less as compared with the values in A and B and this connected with the fact that in C a considerable amount of protein is synthesized and in this synthesis possibly the amino-acids have been utilized. The amide nitrogen including free ammonia shows a very large increase at the end of nine days, the difference in the residual nitrogen is however quite insignificant.

The series D, E and F which received water only show a very striking result in the synthesis of protein. Nitrogen fractions of these series with their respective control analyses are presented in Table XIII as percentage of total nitrogen.

TABLE XIII

Nitrogen as percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control	70·96	29·04	37·72	22·77	14·95	18·32
9 days, water D . . .	60·97	39·03	25·46	10·77	14·69	20·73
Control	67·36	32·64	36·74	23·10	13·64	16·99
6 days, water E . . .	61·69	38·31	29·38	13·77	15·61	16·75
Control	66·81	33·19	35·20	21·08	14·12	17·49
6 days, water F . . .	60·90	39·10	26·41	11·71	14·70	20·43

In the series E and F supplied with water for six days, there is an increase in protein nitrogen with a decrease in amino-acid nitrogen. The discs supplied with water for nine days have synthesized more protein nitrogen than those after six days. The amino-acid nitrogen has diminished to a great extent while the changes in amide and residual nitrogen are small. From the results presented here it is evident that the synthesis of protein has taken place with the disappearance of amino-acid. This increase in protein nitrogen at the expense of amino-acids is also statistically singnificant, while the variations in amide and residual nitrogen are not significant (Table XIV). A comparison between the series receiving ammonium nitrate and the series D, E and F supplied with water only show that the nitrogen absorption in the former has resulted in greater increase in protein nitrogen than in the latter.

The data in this experiment were subjected to the statistical analysis and the standard errors for different nitrogen fractions were calculated from the six control series (Table XI). The mean differences of the nitrogen content after the treatment were tested against the standard errors. The results are presented in Table XIV. (Since the residual nitrogen is estimated from the difference between the total crystalloid nitrogen and the sum of amino and amide nitrogen, its standard error is calculated from the sum of the standard errors of total crystalloid, amino and amide nitrogen).

TABLE XIV

Statistical analysis

—	Total N	Total cryst. N	Protein N	Amino-acid N	Amide N	Residual N
Differences from mean :						
A	*+0·0966	*+0·0976	*—0·0010	*+0·0281	*+0·0386	+0·0077
B	*+0·1828	*+0·1629	*+0·0199	*+0·0276	*+0·0547	*+0·0259
C	*+0·2460	*+0·1980	*+0·0489	+0·0011	*+0·1008	—0·0047
D	+0·0026	*—0·0172	*+0·0198	*—0·0256	—0·0012	+0·0108
E	—0·0038	*—0·0193	*+0·0155	*—0·0189	+0·0002	—0·0018
F	0·0014	*—0·0181	*+0·0195	*—0·0234	+0·0013	+0·0079
Mean of six controls	0·2523	0·1726	0·0797	0·0531	0·0386	0·0423
Variance	0·0000505	0·0000228	0·0000354	0·0000261	0·0000139	..
Standard error	±0·0030	±0·0020	±0·0025	±0·0021	±0·0016	±0·0057

It is apparent that the total nitrogen and the total crystalloid nitrogen have increased significantly as a result of ammonium nitrate supply. The increase in protein nitrogen in all the series except A is highly significant. (In A the increase in protein nitrogen from its own control is more than twice the standard error). Highly significant variation in amino-acids as the result of nitrogen supply and also in the resynthesis of protein is beyond doubt. The amide nitrogen increase due to the supply of ammonium nitrate is highly significant. The differences in the residual nitrogen in general are not significant except in B where a high value is noticed possibly due to nitrate nitrogen as explained before. From the statistical analysis it is clear that the data noted in this experiment indicate a real difference in the nitrogen metabolism as a result of nitrogen supply and also in the resynthesis of protein at the expense of amino-acids.

The respiration rates of these six series are measured after long intervals and the rates are presented in Table XV as mg. of carbon dioxide per gm. fresh weight per hour.

It is noteworthy that along with the absorption of ammonium nitrate in A, B and C there is an increase in the respiration rates. The series receiving ammonium nitrate always show a higher respiration rate than those receiving water only. The rates (C and D) show minor fluctuations in the initial stage and then gradually fall in both treatments, the fall being rapid in D which was supplied with water only. The high level of respiration rate as a result of nitrogen supply reflects the relationship of amino-acids to the respiration rates of Spoehr and McGee

TABLE XV

Respiration rates—mg. of carbon dioxide per gm. fresh weight per hour

—	A Ammon. nitrate	B Ammon. nitrate	E Water	F Water	C Ammon. nitrate	D Water
Period—						
46 hours	0·1294	0·1245	0·1240	0·1097	0·1472	0·1194
92 hours	0·1168	0·1372	0·1010	0·0944	0·1332	0·0991
138 hours	0·1380	0·1400	0·1270	0·0990	0·1457	0·1084
184 hours	..	..	..	..	0·1256	0·0815
206 hours	..	..	..	..	0·1214	0·0726
Mean	0·1281	0·1339	0·1173	0·1010	0·1346	0·0962

[1923] who suggested the accelerating effect of amino-acids on respiration rates. Nitrogen supply has increased the amino-acid content and this possibly maintains the respiration rate high. On this hypothesis of Spoehr and McGee the respiration rate falls in D as the amino-acids disappear in the synthesis of protein.

Table XVI shows the total amount of carbon dioxide produced and the increase in protein nitrogen over the respective controls after the end of the respiration periods.

TABLE XVI

Production of CO_2 and increase in protein nitrogen

—	Total CO_2 in mg. produced per gm. fresh wt.	Increase in mg. of protein-N per gm. fresh wt.	Rate of increase in protein-N per mg. of CO_2 respired
Ammon. nitrate 138 hours (6 days approx.) . A	17·6732	0·064	0·0036
B	18·4736	0·189	0·0102
Ammon. nitrate 206 hours (9 days approx.) . C	28·0490	0·452	0·0163
Water 206 hours D	20·3836	0·263	0·0133
Water 138 hours E	16·1920	0·143	0·0088
Water 138 hours F	13·9426	0·115	0·0083

DISCUSSION

The results presented in this investigation indicate a profound change in the nitrogen substances as a result of increased metabolic activities at the cut surfaces of potato discs. The potato tuber contains a very high percentage of soluble nitrogen–about 79 per cent in the tubers examined; of this a very considerable portion is synthesized into protein when the dormant cells of the tubers are brought to a condition facilitating gas exchange.

The increase in protein nitrogen is related to the oxygen supply as may be seen from the results of experiment I. Under aerobic condition protein content is increased by 22 per cent of total nitrogen while under anaerobic condition 3 per cent is formed. It is interesting, however, that even under these conditions there is a net gain in protein. Temperature appears to play an important part in determining protein synthesis since in experiment II performed at constant temperature 25° C., there is a loss of protein under both conditions and greater loss in protein occurs under aerobic condition. In this case the protein nitrogen has apparently formed residual nitrogen whereas under anaerobic condition there is a large increase in amino-nitrogen. Steward, Wright and Berry [1932] have drawn attention to the effect of the thickness of disc in determining respiration per gm. fresh weight of the disc. They conclude that the active respiring zone is confined to the surface layer of disc, while the inner tissue continues to respire at a normal rate of the uninjured tuber. Experiments on the thickness of disc reported above completely confirm their findings.

The protein synthesis occurs in conjunction with the development of a cork meristem and occurs at the surface only. It might be expected therefore that either (1) the protein synthesis per disc is independent of the thickness of the disc or (2) that the thicker disc would show higher protein synthesis per disc. The first alternative would indicate that oxygen supply is the chief factor in protein synthesis while the second would indicate that mobilization of nitrogen from the deeper layers is important and therefore the thicker disc containing a large reservoir of nitrogen would also show greater synthesis. The data for change in nitrogen fractions as percentage of total nitrogen present as related to disc thickness have been presented in Table XVII. It is seen that the percentage increase in protein is greatest in the thinner disc and rapidly decreases with the thicker disc. Calculated on the basis per disc the increase in protein nitrogen is shown in Table XVII. The total amount of carbon dioxide production on the same basis are entered for comparison.

TABLE XVII

Relation of protein synthesis to disc thickness and respiration

Disc thickness in mm.	Disc weight gm.	Increase in protein-N per disc	Total amount of CO_2 produced per disc per hour
3	2·16	0·00122	0·1443
5	4·26	0·00043	0·1866
10	7·83	0·00037	0·2991

It now appears that the absolute amount of protein is inversely related to the thickness of the disc and to carbon dioxide production. The relation of protein synthesis to disc thickness is

therefore quite different from that of respiration. Question arises as to the cause of the lower protein synthesis in the thicker discs. These have slightly larger surface and larger reserve of nitrogen and therefore neither oxygen supply nor nitrogen reserve will account for the results obtained. The higher carbon dioxide production of the thicker disc is due to the fact that the internal tissues contribute to the carbon dioxide produced. Starch hydrolysis occurs at a layer extending beyond the meristematic region and it is possible that in the thicker disc of sugar formed only a part diffuses to the meristem whereas remainder diffuses into the deeper layers. In the thinner disc therefore all sugar produced by hydrolysis of starch is available for protein synthesis, whereas with thicker disc proportionately less sugar is available for meristem and more is lost in the deeper tissue. That diffusion into deeper layers occurs is shown by Steward's experiments on bromide accumulation. The whole question requires further investigation.

So far condition affecting the nitrogen changes have been discussed and in these changes it has been observed that the increase in protein nitrogen is accompanied by the disappearance of amino-acids. The values for the increase in protein nitrogen and the changes in amino-acid, amide and residual nitrogen are entered in Table XVIII.

TABLE XVIII

Nitrogen as percentage of total nitrogen

Experiment No.	Protein N	Amino-acid N	Amide N	sidual N
I. Control . .	21·08	16·56	19·19	23·98
7 days . .	+22·16	—8·07	—6·22	—0·66
III. Control . .	25·50	19·35	15·51	24·13
3 days F . .	+15·88	—3·91	—2·87	—6·23
6 days E . .	+26·15	—8·59	—4·61	—8·34
V. Control . .	32·92	22·09	13·88	17·24
6 days . . .	+5·79	—9·35	+1·28	+1·35
Control . . .	29·04	22·77	14·95	18·32
9 days . . .	+9·99	—12·00	—0·26	+2·41

It is seen that the increase in protein nitrogen is always accompanied by the disappearance of amino-acids. This loss in amino-acids in the potato discs may be due to two reasons (1) either the amino-acids are resynthesized back to protein by condensation or (2) it is due to the oxidative deamination to produce ammonia which unites with the carbohydrates to form protein. Since it has been shown by the author [Sircar, 1936] that deamination does not depend on the concentration of carbohydrates present, there is the possibility of deamination in the potato discs as a consequence of increased metabolic activities. An argument against the first reason may be suggested, namely that if the loss in amino-acids were directly responsible for the condensation of amino-acids to protein, then the greatest loss in amino-acids would be found in those cases where the greatest increase in protein nitrogen is attained. This is not the case. Table XVIII shows that in experiment V the loss in amino-acids is greater than in experiments III or I, where more protein is synthesized. Since the loss in amino-acids is not equivalent to the protein formed, it must mean that loss has occurred the other way by oxidative deamination. Further, it is also evident that the loss of amino-acids is more in those cases where there is more production of carbon dioxide. The amount of carbon dioxide produced and the loss in amino-acids in the series receiving water in two experiments are shown in Table XIX.

TABLE XIX

Production of CO_2 and loss in amino-acid nitrogen

—	Total CO_2 mg.	Loss in amino-acid N mg.	Loss in mg. per mg. of CO_2
Experiment III E .	10·70	0·193	0·018
Experiment V E & F	15·0673	0·255	0·017

A comparison between experiments III and V shows that in the latter an increased carbon dioxide production accompanies a greater loss in amino-acids than in experiment III. The increased carbon dioxide production must have occurred through the greater loss in amino-acids since the carbohydrate supply in both the cases is the same. Under anaerobic condition it has been shown that the synthesis of protein is small and has increased to the same extent as the amide has disappeared (Table II).

It is seen that the amino-acids have not disappeared, on the contrary, there is an accumulation from proteolysis. This increase in amino-acids shows that there is no deamination, otherwise either the amino-acids would have been lost or the ammonia set free during the process would be free or form amide and the level of amide nitrogen would have been raised further. Since it is found that the increase in protein nitrogen is only equal in extent to the disappearance of amide this may mean that in absence of deamination the synthesis of amide is inhibited and consequently protein level is not increased. Hence from these considerations it may be suggested that the amino-acids are not resynthesized into protein, the disappearance is due to the oxidative deamination, which sets free ammonia to form

the amide, and from the amide the protein is synthesized.

The supply of inorganic nitrogen to the potato disc has resulted in an accumulation of nitrogen (Tables XI and XII) and metabolic activities of these cells as measured from the increased carbon dioxide production are also increased (Table XVI). It is seen that a considerable portion of absorbed nitrogen remains in the soluble form. The synthesis of protein from the addition of inorganic nitrogen is shown. The absorption of nitrogen and the synthesis of protein from this added nitrogen increased with time. As compared with six days the protein nitrogen and the soluble nitrogen have both increased at the end of nine days (Table XII, C). Since no separate estimations of nitrate nor ammonia were made, nothing could be said from the data presented as to the relative absorption of anion and cation. In series A and C (experiment V) receiving ammonium nitrate, there is no increase in residual nitrogen which includes the presence of nitrate nitrogen. It means that either nitrate has not been absorbed or has been used up in metabolism. In B (Table XII) the increase in residual nitrogen is shown and is explained to be possibly due to nitrate nitrogen. From this it may be said that nitrate also is absorbed in A and C, and has been metabolized. The course of amide metabolism in the series receiving ammonium nitrate is not exactly known as the amide figures presented here include the possibilities of unmetabolized ammonia. The amino-acids in these three series show a remarkably higher value than the series not receiving extra nitrogen (Table XI). The increased amino-acids are possibly due to the accumulation of amino-acids derived from proteolysis. In these series the metabolic activities of the cells are increased as evident from the enhanced carbon dioxide production (Table XVI). In response to this the process of synthesis would be expected to increase and this increase in the synthesis is noticed from a reference to Table XVI (B and C) where it has been shown that the increase in protein nitrogen per mg. of carbon dioxide respired is greater than the corresponding series receiving water only. As the synthesis is increased the proteolysis would also be expected to have increased since these two processes occur concurrently. The increase in amino-acids may thus be explained in the discs receiving added nitrogen.

Summary

An apparatus is designed to maintain simultaneously the necessary conditions for allowing discs of potato tuber to respire aerobically for a considerable time in an atmosphere free from carbon dioxide accumulation, and for salt absorption and water supply to the transpiring cells without interfering with aeration and carbon dioxide measurement during the course of an experiment.

Discs of potato tuber (var. King Edward VII) contain a high percentage of soluble nitrogen—a maximum of 79 per cent of total nitrogen in the tubers examined ; of this a considerable portion is synthesized to protein when the dorment cells of the tuber are exposed to a condition of free gas exchange. The increase in protein nitrogen is related to oxygen supply and increased carbon dioxide production.

In the synthesis of protein the behaviour of nitrogen fractions, namely amino-acids and amides, have been studied. That the disappearance of amino-acids in protein synthesis is due to the process of oxidative deamination to set free ammonia to form amide which synthesizes protein has been suggested.

Absorption of inorganic nitrogen and metabolism of this into protein and other soluble organic nitrogen have been noted in the discs. These changes are accompanied by increased respiration rate.

Acknowledgements

The author desires to express his gratitude to Prof. V. H. Blackman, Sc.D., F. R. S., for granting facilities to carry out this investigation at the Imperial College of Science and Technology, London, and to Prof. F. G. Gregory, D.Sc., F. R. S., for suggesting the problem, continued inspiration and encouragement.

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A CANKER OF APPLE TREES IN MYSORE

By B. B. MUNDKUR and K. F. KHESWALLA, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 17 September 1942)

(With Plate XVI)

Twigs of young apple (*Pyrus Malus* L.) trees affected by a canker were recently sent by the Director of Horticulture, Mysore State, for determination of the causal organism. The plants were imported from Australia and the canker appeared on them within a fortnight of receipt. The canker is due to a fungus known to pathologists as *Sphaeropsis Malorum* Berk. which has been recorded for India by Butler and Bisby [1931]. Specimens of cankered pear (*Pyrus communis* L.) twigs from Kumaon, recently deposited in the Herb. Crypt. Ind. Orient. by Mr U. B. Singh, Research Assistant Mycologist, Chaubattia, also bear the name '*Sphaeropsis Malorum* (*Haplosporella*)', but without authorities. As there is some confusion in the nomenclature of the fungi belonging to the genus *Sphaeropsis* and causing cankers in apples and pears and as *Sphaeropsis Malorum* Berk. has evidently been introduced into Mysore with the apple stocks from Australia, its record for India by Butler and Bisby [1931] being based on an error, a description of the fungi causing the canker is reported in this note.

There are two distinct fungi bearing the name *Sphaeropsis Malorum*, viz. *S. Malorum* Berkeley and *S. Malorum* Peck, and though these names have been superseded by the names applied to their perfect (ascus) stages, they persist among pathologists because of their long and constant usage in pathological literature. The name was first applied by Berkeley in 1836 to a fungus found by him in decayed apples in England and Peck used it, with Berkeley as authority, for a fungus causing a black rot of apples in New York State. The spores of Berkeley's fungus were hyaline while those of Peck's were brown. Saccardo accordingly renamed Berkeley's fungus *Phoma Malorum* (Berk.) Sacc. and used the name *Sphaeropsis Malorum* for the New York fungus, citing Peck as the authority. This manner of changing names is in contravention of the Rules of Botanical Nomenclature as at present understood and this has led to considerable confusion. The discovery of the perfect stages of these two fungi by N. E. Stevens [1933, 1936] and a careful examination of the type specimens of the related fungi by him and by Petrak and Sydow [1926] have helped a great deal in stabilizing the nomenclature of these fungi. It may be added that the genus *Sphaeropsis* itself has been partly merged into *Haplosporella* and partly into *Botryodiplodia*, as a synonym.

Both the fungi have identical stromatic characters but they show constant differences in the characters of the pycnospores. The spores within the pycnidium in Berkeley's fungus are hyaline, non-septate, and relatively thick-walled, walls appearing glassy under the microscope. They are regular in shape and according to N. E. Stevens [1933], measure $22\text{-}33 \times 9\text{-}13\mu$, mostly $23\text{-}29 \times 9{\cdot}5\text{-}10\mu$. When the cankered twigs are incubated, the pycnidia burst out of the cortical parenchyma in which they are embedded and slender spore tendrils are exserted out of the ostiole, at which time the spores become brown or tan coloured and 1-septate and measure $20\text{-}27 \times 10\text{-}16\mu$, mostly $25\text{-}27 \times 10\text{-}12\mu$ (Stevens) (Plate XVI, fig. 3).

As against these characters, the spores of Peck's fungus are uniformly tan to brown within the pycnidium itself and as a rule irregular in shape. A small percentage may be 1-septate but there is no difference in the colour of the septate and non-septate spores. Stevens [1933] gives the measurement as $24\text{-}30 \times 12\text{-}18\mu$, mostly $25\text{-}27 \times 12\text{-}13\mu$. (Plate XVI, fig. 4).

It will be noted that the chief differences between the two fungi are in the shape, size, septation and particularly the time of colouring of the spores. This difference in the time of colouring is so constant that Petrak and Sydow [1926] consider it the most reliable diagnostic character for distinguishing *Botryodiplodia Malorum* (Berk.) Petr. and Syd., the name applied by them to Berkeley's fungus, from *Haplosporella Mali* (Westend.) Petr. and Syd., the name given to Peck's fungus. It may be further added that all these names are now superseded by the names applied to the ascus stage which according to N. E. Stevens [1933, 1936] are *Physalospora mutila* (Fries) N. E. Stevens and *Physalospora obtusa* (Schw.) Cooke, respectively.

Sphaeropsis Malorum Berk., recorded by Butler and Bisby [1931] for India, is based on a report of its occurrence on a rotten apple by Mitter and Tandon [1929] who presumed that it came from Kulu. Of the two isolations made by them, one formed pycnidia in culture media. These were dark brown, immersed in the substratum and contained olive-brown, non-septate conidia of uniform size. The culture was submitted to Dr A. S.

Horne, Imperial College of Science, London, who is reported to have stated that it resembled '*Sphaeropsis Malorum*', but he was not definite as his own culture of the fungus was not sporing and an accurate comparison was not possible. It will be admitted that that is hardly enough evidence to record *Sphaeropsis Malorum* Berk. for India.

The fungus occurring on the Australian apple stocks in Mysore (Plate XVI, fig. 1) is undoubtedly Berkeley's fungus, for the pycnidia contained hyaline, large-granuled, regular-shaped spores with thick, glassy walls, which become tan or brown and 1-septate after being extruded out of the pycnidia (Plate XVI, fig. 3). They are slightly shorter and a little broader than the European form, the hyaline and non-septate spores being $14 \cdot 4$-$23 \cdot 4 \times 10 \cdot 8$-$14 \cdot 4$M and 1-septate and brown spores being $16 \cdot 2$-$23 \cdot 4 \times 9 \cdot 0$-$12 \cdot 6 \mu$. It may be added that both the hyaline and the brown spores freely germinate within 24 hours if suitable conditions are provided and all attempts made so far to obtain the ascus state in culture have proved futile. Both *Sphaeropsis Malorum* Berk. and *Sphaeropsis Malorum* Peck have been recorded for Australia byNoble, Hynes, McCleery and Birmingham [1934], the latter being designated *Physalospora Cydoniae* Arnaud, on pears and apples respectively.

That the fungus is a new introduction from Australia on imported apple stocks is therefore more than likely. The Mysore fungus bears a certain resemblance to *Glutinium macrosporum* Zeller which according to Zeller [1927] causes a canker of apple and pear trees in Oregon. Its pycnidia are covered with a white, flaky exudate in dry weather, giving the black pycnidia a white sheen. When full grown, they are almost superficial. The conidiophores are simple or slightly branched as against the simple conidiophores in *Sphaeropsis Malorum*. The conidia are hyaline, 1-celled and exude at the apex, in the form of flinty, translucent globules and never become 2-celled or coloured.

A specimen of '*Sphaeropsis Malorum*' collected in the Nilgiris in 1915 is available in the Herbarium of the mycology section at Coimbatore. The specimen is at present without any conidia and it is not possible to say whether the identification is correct. A canker of pear trees is reported to be doing over 35 per cent damage in Kumaon (Plate XVI, fig. 2). The fungus responsible for that canker, specimens of which were kindly made available by Mr U. B. Singh, is not *Sphaeropsis Malorum* Berk. and it does not appear to be *Sphaeropsis Malorum* Peck, for though the spores are of the *Haplosporella* type, the fungus is intimately associated with its ascus stage which is not *Physalospora obtusa* but a fungus belonging to Cucurbitariaceae and is perhaps a species of *Otthia*. All efforts that were made to germinate the conidia which are always coloured, and the ascospores of this fungus have so far given negative results.

In a few infection experiments that were conducted, it was noted that the Mysore fungus can cause a severe rot of apple fruit and that it is able to attack twigs of pear.

We would like to express our thanks to Mr H. C. Javaraya, Director of Horticulture, Mysore State, for furnishing the specimens.

Summary

This note records the occurrence of *Sphaeropsis Malorum* Berk. [*Physalospora mutila* (Fries) N. E. Stevens] on imported apple plants in Mysore. It also shows that the previous records of the occurrence of this fungus in India are based on error.

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**Postscript*

Since the above was sent for publication, Mr. E. W. Mason of the Imperial Mycological Institute, Kew, wrote to say that the spores of the Mysore specimen of *Sphaeropsis* are consistently smaller than those of the European species of *Sphaeropsis Malorum* Berk. It was considered desirable, therefore, to compare the Mysore fungus with a specimen from Australia, which became possible through the courtesy of Dr C. J. P. Magee, who kindly sent two diseased twigs collected in Australia in 1925. A comparison indicates that both the Mysore and the Australian species are one and the same. The measurements of the unextruded spores are given below:

Type specimen, measurements by E. W. Mason: 23-28×10-12μ

Australian specimen, authors' measurements: $14 \cdot 4$-$23 \cdot 4 \times 9 \cdot 2$-$14 \cdot 4 \mu$

Mysore specimen, authors' measurements: $14 \cdot 4$-$23 \cdot 4 \times 10 \cdot 8$-$14 \cdot 4 \mu$

Because of these differences in the measurements of the type specimen and the Mysore specimen, Mr Mason is certain that the latter is not Berkeley's fungus. But there is little doubt that it is same as the Australian species. On the second twig sent by Dr Magee we have found perithecia and 8-spored asci, possibly the *Physalosprao* stage of the fungus. [AUTHORS].

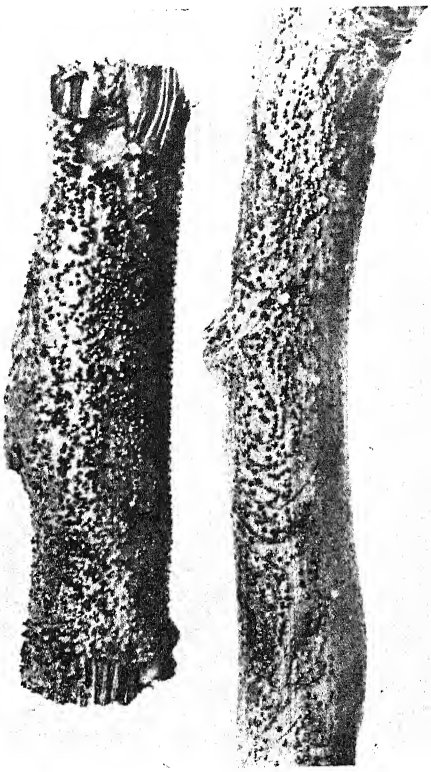


FIG. 1. Apple twigs affected by *Sphaeropsis Malorum* Berk. from Mysore (×2)

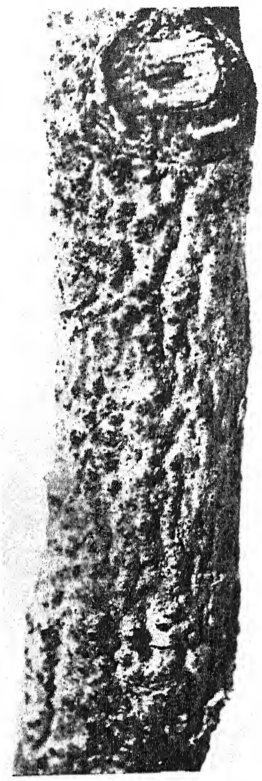


FIG. 2. Pear twigs affected by *Haplosporella* sp. and *Otthia* sp. from Kumaon (×2)

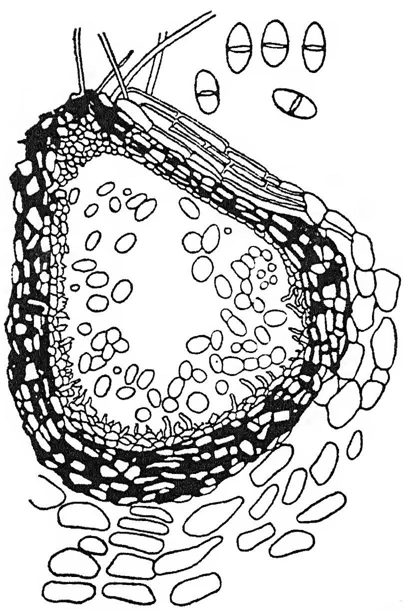


FIG. 3. Pycnidium of *Sphaeropsis Malorum* Berk. Hyaline 1-celled spores within and brown 2-celled spores outride

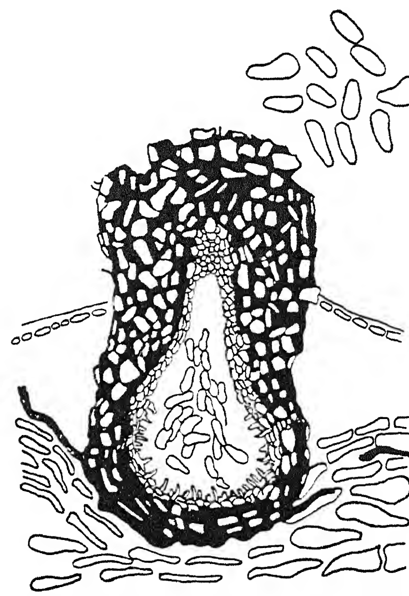
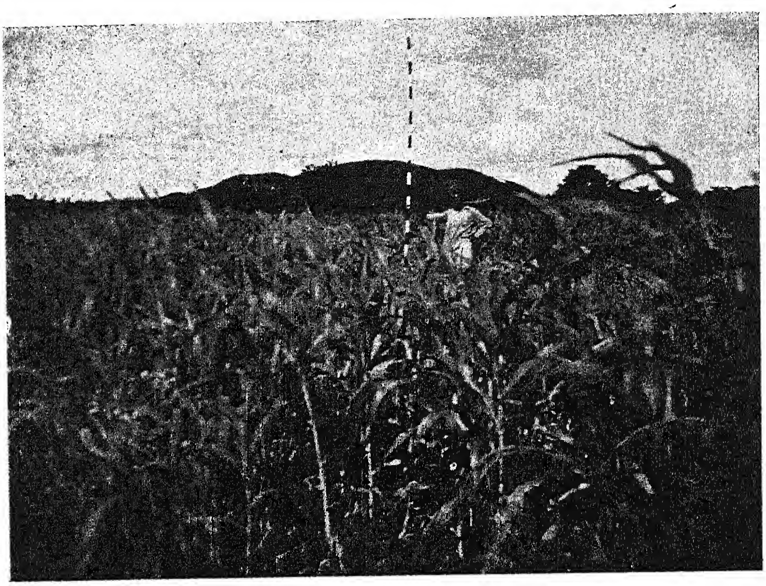


FIG. 4. Pycnidium of *Sphaeropsis Malorum* Peck after Hesler. (Note hyaline and brown spores which are irregular in shape)



Graduated rod placed inside the *jowar* crop for measuring its height

STUDIES ON THE ESTIMATION OF GROWTH AND YIELD OF *JOWAR* BY SAMPLING *

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(Received for publication on 14 October 1942)

(With Plate XVII and four text-figures)

In the past agricultural and meteorological statistics were collected mainly for certain general administrative and technical purposes respectively. While useful for those purposes, these data have proved to be inadequate for a detailed examination of the effect of weather on the development and yield of a crop. It is now realized that more precise estimations of the crop's growth characteristics and yield on the one hand and measurements of the actual local or micro-climate of the crop on the other are necessary if real progress is to be made in agricultural meteorology.

The simultaneous recording of the growth and the ' micro ' or local climate of a crop naturally had to await the recent advances in (1) the methods of random sampling as applicable to the estimation of crop growth and yield and (2) the new science of micro-climatology or the meteorology of the air and soil layers very near the ground surface in which crops have their existence.

Since 1929, under the inspiring leadership of Prof. R. A. Fisher the application of modern statistical methods to the problems of estimating the growth characters and yield of crops has made rapid strides. A number of workers, e.g. Clapham [1929 ; 1931], Kalamkar [1932], Yates and Zacopanay [1935], Barnard [1936], Fairfield Smith [1938] and very recently Hudson [1939 ; 1941] have made numerous important contributions to the subject in Great Britain.

It is clear that, for a short cereal crop like wheat, the sampling technique developed in Britain will require only slight modification to suit Indian conditions. On the other hand, in India, we have to deal with many tall crops like *jowar*, sugarcane, etc. and for such crops a suitable sampling technique has to be evolved.

Since 1932, the Agricultural Meteorology Section has been engaged in developing suitable sampling technique and recording precision observations on important Indian crops. Kalamkar and Gadre [1936] recorded precision observations on wheat at Poona. They found (1) the plant number in the field at the time of harvest was only about 16 per cent of the number of seeds sown (2) Tillering reached the maximum value of 5·3 shoots to each plant but before harvest this came down to 4. (3) About 90 per cent of the shoots had put forth earheads before harvest and the average number of ears per plant was 3·5. (4) The estimated yields of grain and straw were 25·5 gm. and 49·0 gm. per metre respectively while the actual yields were 23·3 gm. and 50·5 gm. respectively.

Some crop-cutting experiments on the estimation of wheat yield by sampling were conducted by the Agricultural Meteorology Section with the kind co-operation of the Deputy Director of Agriculture, Jubbulpore, at the Government Experimental Farm, Powarkheda, Central Provinces. It was found that a unit of the order of 16 square yards appears to be suitable for sampling operations on wheat. It was also found that there is no material gain in information by sampling more than about 16 per cent of the crop and that the units elongated across the rows are less variable than those elongated along the rows. The data are being discussed in detail in another paper to be published shortly. The Agricultural Meteorology Section also conducted precision observations on rice (a short crop) at Karjat for the last seven years with the kind co-operation of Dr B. S. Kadam, Crop Botanist to the Government of Bombay. A paper discussing the results obtained is under publication. The important findings may, however, be briefly stated here. The number of culms increases and attains a maximum value by the sixth or seventh week after transplantation, remains more or less constant for about a fortnight and then decreases due to some of the late-formed tillers dying out. The period of quickest growth of the crop as indicated by its height is from the 8th to the 13th week after transplantation. The height attains its maximum value by the 13th week and remains constant thereafter. The percentage differences between actual and estimated yields are in general quite small.

In the present paper we shall discuss the results of some preliminary sampling experiments on *jowar*, a tall crop.

* Summary of a thesis for the M.Sc. degree submitted to the University of Madras

Precision observations on *Jowar*

Materials and methods. All the observations were taken on the *jowar* crop grown in the Agricultural College Farm, Poona. In 1940 germination observations were taken in *kharif jowar* (Nilwa variety). Developmental observations and harvesting experiments were done with *rabi jowar* (variety—Shalu Maldandi) during the clear seasons of 1940-41 and 1941-42. In all experiments the crop was studied by the method of random sampling, fresh samples being selected on each occasion. About 5 per cent of the crop was selected for each day's observation.

The 'sampling unit' consisted of two constituent one-metre lengths along a row separated by an interval of half-a-metre. The measuring rod was of the form shown below :

1 metre	½ metre	1 metre
observe	omit	observe

To facilitate the recording of observations, three inch nails at the end of each metre were projected horizontally to mark out individual metres exactly.

The following observations were taken on the plants in each metre length :

(*a*) Germination. The number of seedlings visible above the ground.

(*b*) Developemental observations :

(*i*) number of plants,
(*ii*) number of shoots,
(*iii*) number of fully expanded green leaves,
(*iv*) height of shoots up to the base of the fully expanded topmost leaf, and
(*v*) number of emerged earheads.

The field was sub-divided into four plots and 20 samples (i.e. 40 metre lengths) were taken from each plot so that the total number of metre lengths for each day of observation was 160. The allocation of the degrees of freedom was as follows :

Plots	3
Between samples	76
Within samples (between metres) . .	80
Total .	159

The analysis of variance for the number of shoots on 23 October 1940 is given in Table I to illustrate the method of analysis followed. Sampling error of the mean was obtained by taking the square root of the variance 'between samples' after dividing it by the total number of metres (160 in this case) under observation.

TABLE I

Analysis of variance for number of shoots per metre

(Observations on 23 October 1940)

Factor	Degrees of freedom	Variance
Plot	3	92·5
Between samples . .	76	117·2
Within samples . .	80	47·6
Total .	159	81·7

Sampling error for the mean =

$$\sqrt{\frac{117\cdot2}{160}} = 0\cdot855$$

(*c*) Harvesting experiments. For the estimation of the yield by sampling another structure of the sampling unit was also tried in addition to the one used in developmental studies as described above. This second method consisted in selecting two parallel metre lengths one from each of two adjacent rows to constitute one sampling unit as shown below :

$$\left.\begin{array}{ll}\text{One row} & 1 \text{ metre}\\ \text{Adjacent row} & 1 \text{ metre}\end{array}\right\} \text{under observation.}$$

This method will be called the 'parallel' method for convenience. When the crop was ready for harvest, samples were cut, bundled into sheaflets and dried. The dry weights of straw and of grain from each ultimate unit (metre in this case) of the sample were recorded and analyzed statistically.

(*d*) In 1941-42 in addition to the above experiments 110 individual plants were selected at random and bagged soon after setting. Height of plants as well as the diameter at one-fourth, half and three-fourths heights were measured when the crop appeared to be fully grown. When the crop was ready for harvest, the selected plants were cut close to the ground and weighed individually. Grains were removed and the weight of grain recorded.

Discussion of growth records

(*a*) *Germination study in* kharif jowar. The crop was sown on 6 July 1940 and germination counts were taken between 10 and 22 July. Table II gives the mean number of germinated seeds per metre together with the sampling error of the mean.

The sampling error of the mean =

$$\frac{\sqrt{\text{Variance between samples}}}{\sqrt{\text{Total number of metres}}}$$

TABLE II

Mean values of germinated seeds and sampling error of the mean

(Sown on 6 July 1940)

Date	Mean per metre	Sampling error of the mean
10 July 1940 . .	8·700	0·403
11 ,, ,, . .	13·125	0·688
12 ,, ,, . .	12·963	0·724
13 ,, ,, . .	14·025	0·642
17 ,, ,, . .	15·719	0·738
18 ,, ,, . .	14·213	0·548
22 ,, ,, . .	14·481	0·642
1 Aug. ,, . .	10·350	0·435

Fig. 1 shows graphically the mean number of seedlings per metre length of row on each day.

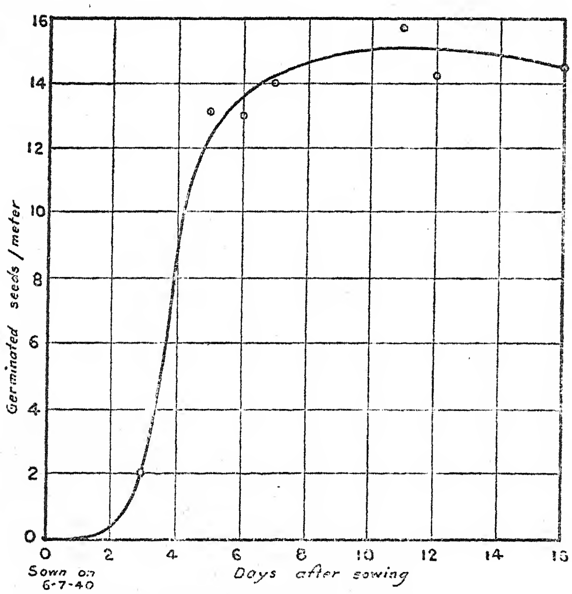

FIG. 1. Variation of number of germinated seeds per metre

It will be seen from Fig. 1 that the maximum number of germinated seeds is 15·72 as compared to 23·7 for 100 per cent germination. So the maximum germination percentage was only 66·3 under field conditions, the remaining 33·7 being accounted for by non-viability or late or unsuccessful germination or loss due to birds and insects. The first seedlings made their appearance above ground on the third day after sowing and the number of germinated seeds increased abruptly on the fifth day indicating that 'the grand period' of germination comes between the fourth and sixth day after sowing. The daily increase in the number of seedlings before and after the above grand period was not found to be significant statistically. Twenty-seven days after sowing, the plant number came down to 10·35 per metre. It appears from Fig. 1 that 50 per cent of the maximum germination occurred 3 days 21 hours after sowing. This then is the period for germination according to the current convention.

There are three stages in the germination of the crop, (1) a period of slow germination, just after sowing, lasting for two to three days, (2) a period of rapid germination starting from the end of the first period and continuing till 11 days after sowing and (3) a gradual fall in the seedling number due to dying off of some of the weaker seedlings from crowded spots of the field.

The last column in Table II gives the sampling error as obtained by analyzing the data by the method indicated in Table I.

(*b*) *Growth of the crop*

Rabi *crop, 1940-41.* Table III shows the frequency distribution of the number of shoots per metre. The maximum value for each day is given in italics. It is interesting to observe the very wide fluctuation of shoot number per metre during the period of maximum tillering. At the end of this period the variability in the number of shoots per metre comes down.

Table IV gives the mean values of different plant attributes as well as the shoot to plant ratio together with sampling errors of the means. The variation with time of the mean values for the plant attributes is shown graphically in Fig. 2.

Plants. The estimated average number of plants per metre assuming 100 per cent germination is 69 while 35 days after sowing the actual number of plants per metre is only 7. This clearly shows that only 10 per cent of the total number of seeds sown survived as plants. The decrease in plant number from this date is not appreciable as is seen from the fact that after 89 days the mean number of plants per metre is 5·2. The decrease in plant number is accompanied by a slight fall in sampling error.

Shoots. Thirtyfive days after sowing the shoot number was 14·77. This fell to 6·90, 80 days after sowing. This fall is fairly uniform with respect to time as seen from Fig. 2. The sampling error also shows a tendency to fall The shoot to plant ratio was 2 on 28 October 1940 and came down to 1·3 on 21 December 1940

TABLE III

Rabi jowar *1940-41*

The frequency distribution of the number of shoots per metre

Days after sowing	Date	Number of shoots per metre																		Mean No. of shoots per metre	Remarks
		0-2	3-5	6-8	9-11	12-14	15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42-44	45-47	48-50	51-53		
30	23 Oct. 1940 .	5	14	16	17	*27*	22	22	18	5	5	2	4	2	0	1	0	0	0	13·53	Maximum tillering
35	28 ,, ,, . .	10	19	13	15	*33*	27	13	12	8	5	0	0	3	0	1	1	0	0	14·17	
43	5 Nov. ,, . .	13	17	*27*	21	22	17	17	9	8	4	3	1	0	0	0	0	0	1	12·75	
53	15 ,, ,, . .	17	27	*32*	28	24	9	11	6	5	1	0	0	0	0	0	0	0	0	9·83	
60	22 ,, ,, . .	12	*33*	30	23	23	16	9	7	4	0	1	0	2	0	0	0	0	0	10·41	
72	4 Dec. ,, . .	29	26	*37*	29	16	11	6	3	2	0	0	0	0	0	1	0	0	0	8·36	
80	12 ,, ,, . .	28	*42*	38	22	22	6	0	1	1	0	0	0	0	0	0	0	0	0	6·90	
89	21 ,, ,, . .	25	*47*	38	29	10	9	2	0	0	0	0	0	0	0	0	0	0	0	6·77	
119	20 Jan. 1941 .	15	19	*23*	11	6	3	1	2	0	0	0	0	0	0	0	0	0	0	6·91	From 80 metres. Crop harvested

TABLE IV

Rabi *crop 1940-41*

(Sown on 24 September 1940)

The mean values of plant attributes and their sampling error

Days after sowing	Date	Number of shoots		Number of plants		Number of leaves		Height in cm.		Number of ears		Shoot to plant ratio	Remarks
		Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.		
30	23 Oct. 1940	13·53	0·855	...	...	...	...	...	...	...	...	...	
35	28 ,, ,, .	14·17	0·754	6·98	0·367	3·66	0·073	17·71	0·603	...	...	2·030	Maximum tillering ; infested with pyrilla
43	5 Nov. ,, .	12·75	0·705	7·34	0·384	3·63	0·096	28·05	1·145	...	...	1·733	Growth in height has commenced
53	15 ,, ,, .	9·83	0·617	...	...	3·94	0·128	45·94	2·444	...	...	...	
60	22 ,, ,, .	10·41	0·655	6·43	0·349	4·72	0·151	62·67	2·900	...	...	1·619	
72	4 Dec. ,, .	8·36	0·592	5·76	0·324	6·39	0·181	110·58	4·213	1·98	0·195	1·451	Ears emerging
80	12 ,, ,, .	6·90	0·433	5·23	0·275	6·21	0·169	125·32	4·534	3·58	0·263	1·319	Bottom leaves drying off
89	21 ,, ,, .	6·77	0·377	5·20	0·265	6·01	0·141	134·79	3·713	4·93	0·286	1·302	
119	20 Jan. 1941	6·91	0·617	...	...	...	...	...	...	6·12	0·529	...	Crop was harvested. Values of two plots (N. W. and S. W. only

S. E. = Sampling error of the mean

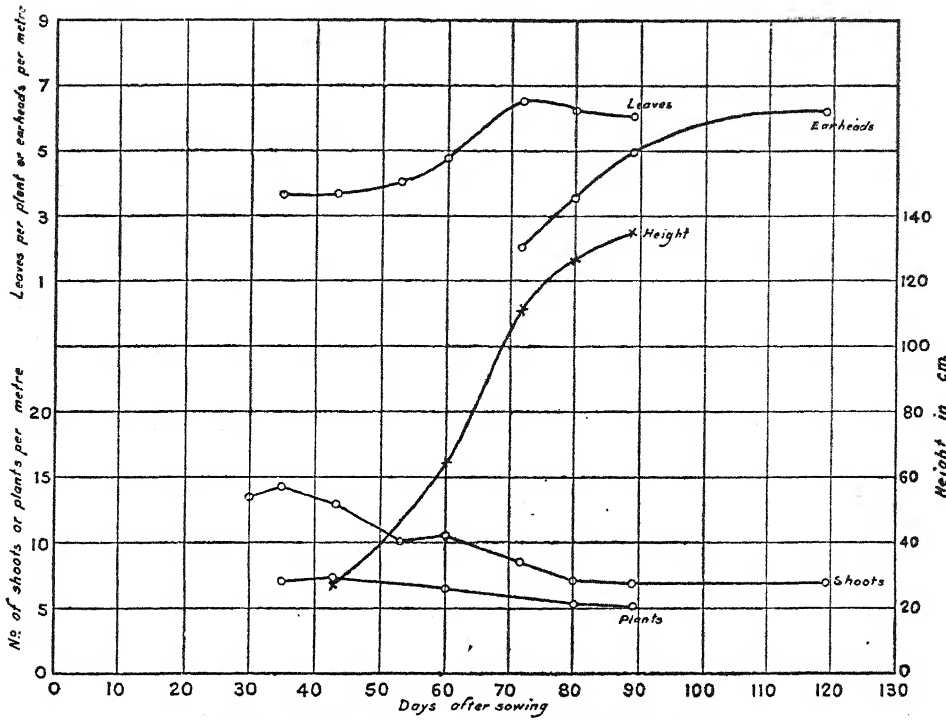

FIG. 2. Plant attributes for the *rabi jowar* 1940-41

when the crop is 89 days old. This indicates that the percentage of shoots dying out is greater than that of the plants.

Leaf. The number of green leaves goes on increasing and attains a maximum value of 6·4 about 72 days after sowing. There is a gradual fall in the leaf number later on as the lower leaves begin to turn yellow. The sampling error of the mean increases with the increase in leaf number and later decreases as the number of leaves falls down.

Height. It is interesting to note from Fig. 2 that the height curve is S-shaped and the rapid growth in height starts soon after maximum tillering is reached, and practically ceases with ear emergence. This rapid growth occurs between the 8th and the 11th week from sowing. The maximum height attained is 134·79 cm. when the crop is 89 days old. The sampling error of the mean increases and is high during the grand period of growth but comes down subsequently when all the plants attain their maximum heights and the crop becomes more uniform.

Earheads. Earheads were found to emerge 68 days after sowing ; before harvest the mean number of earheads per metre was 6·12. The sampling error of the mean increases with the increase in the number of earheads. It may be noted that the mean number of shoots and ears per metre are of the same order, suggesting that most of the shoots put forth ears. Actually nearly 88·6 per cent of the shoots in the field did so.

Covariance between shoots and tillers. We noticed in Table III a large variability in the number of shoots per metre. To find out whether there is any relation between the plant number (X) and the number of tillers (Y) (shoots minus plant number) per metre the covariation between them has been worked out. Table V gives the analysis of covariance of plants to tillers.

TABLE V

Analysis of covariance of plants to tillers

Due to	D. F.	S. P. (XY)	Covariance	S (X2)	S (Y2)	$\gamma = \frac{S(xy)}{\sqrt{S(x^2)\,S(y^2)}}$
Plots .	3	—24·1	—8·03	49·1	15·5	...
Between samples .	76	1557·4	20·50	1635·8	2166·0	0·8273*
Within samples .	80	790·5	9·88	849·0	1533·5	0·6928*
Total .	159	2323·8	14·62	2533·9	3715·0	

D. F.=Degrees of freedom S. P.=Sum of products

*Significant at 1 per cent level

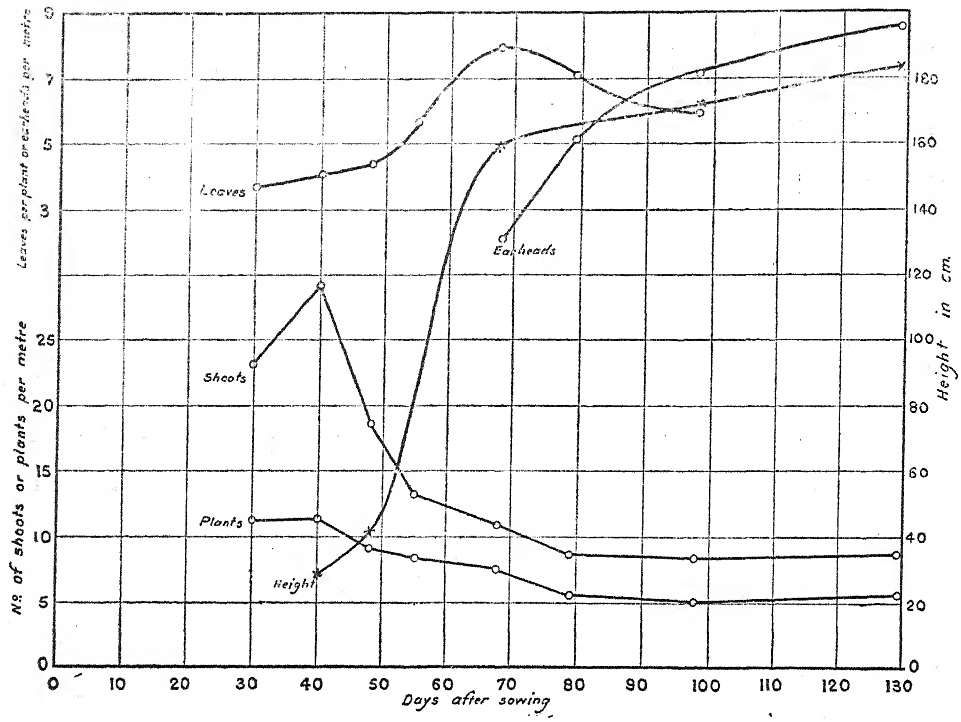

FIG. 3. Plant attributes for the *rabi jowar* 1941-42

It was found that the correlation is highly positive showing that a greater number of plants gives rise to a greater number of tillers. The capacity for tillering does not therefore seem to have been affected sensibly by the density of the population within the range of plant population occurring in the field.

Rabi *crop, 1941-42*. Table VI gives the mean values of different plant attributes and their sampling errors for the crop of 1941-42. These values are shown graphically in Fig. 3.

Plants. This year also the same seed rate as in the previous year was employed and the maximum mean number of plants per metre was 11·36, 40 days after sowing as compared with the previous year's corresponding figure of 7·34 plants per metre, 43 days after sowing. This definitely shows that the population was more in the *rabi* crop of the year 1941-42 and 16·2 per cent of the seeds sown had survived to this date. There is a gradual fall in the plant numbers and before harvest it has come down to 5·6, a decrease of nearly 50 per cent. The sampling error of the mean number of plants steadily decreases with the decrease in plant number except on 4 November 1941.

Shoots. The above tendency holds good for shoot number also. These are in accordance with the previous year's observations excepting that the mean values on corresponding dates are higher and the percentage of sampling errors calculated from the sampling errors are lower. The reason for this is that the field in which precision observations were taken in 1941-42 was more fertile and homogeneous than that in the previous year.*

The shoot to plant ratio of the 1941-42 crop reaches a maximum value of 2·55 as against 2·03 in 1940-41. This is followed by a fall. The ratio comes down to 1·56, 55 days after sowing and this is kept up till harvest. Thus the better fertility of the field is reflected also in the larger number of tillers in 1941-42.

Leaves. The mean number of leaves per shoot increases steadily until a maximum value of 7 94 leaves per shoot is reached, 68 days after sowing. In the previous year the maximum number of green leaves was 6·39. This also may be due to the better quality of the field in 1941-42. Later

* The weather conditions during the period of vegetative growth of the two *rabi* crops (1940-41 and 1941-42) were critically examined. For all practical purposes they were found to be more or less similar. The field in which the second year's crop was grown is more fertile, homogeneous and deeper than the previous year's field. The climatic conditions became dissimilar during the blooming period. This will be discussed in a later section.

TABLE VI

Rabi *crop 1941-42*

(Sown on 18 September 1941)

The mean values of plant attributes and their sampling error

Days after sowing	Date	Number of shoots		Number of plants		Number of leaves		Height in cm.		Number of ears		Shoot to plant ratio	Remarks
		Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.		
30	17 Oct. 1941.	23·01	1·374	11·22	0·515	3·68	0·071	...	...	...	...	2·06	
40	27 ,, ,, .	29·11	1·513	11·36	0·554	4·06	0·084	28·2	1·304	...	...	2·55	Maximum tillering. Pyrilla observed in large numbers
48	4 Nov. ,, .	16·16	1·371	9·24	0·708	4·34	0·118	40·3	2·255	...	...	1·75	Rapid growth commences
55	11 ,, ,, .	13·09	0·943	8·44	0·541	5·64	0·123	87·5	3·850	...	...	1·56	
68	24 ,, ,, .	10·79	0·815	7·45	0·463	7·94	0·193	158·5	5·633	2·04	0·241	1·45	Ear emergence
79	5 Dec. ,, .	8·51	0·631	5·66	0·372	7·07	0·203	163·8	5·987	5·11	0·432	1·50	Lower leaves drying off
98	24 ,, ,, .	8·20	0·558	5·05	0·287	5·93	0·173	169·4	4·573	7·10	0·787	1·62	Observations were taken only on Northern plot
129	24 Jan. 1942.	8·79	0·573	5·66	0·317	...	...	182·2	6·520	8·51	0·588	1·55	Crop harvested. Practically all leaves have dried up

S. E. = Sampling error of the mean

it comes down to nearly 6, 98 days after sowing. The sampling error increases with increase in leaf number and shows a fall on the last day of observation.

Height. The mean height of shoots was low till the crop was seven weeks old. Then the grand period of growth commenced and lasted for slightly more than two weeks. The maximum height attained was 182·2 cm. on the day of harvest as against 134·79 cm. in the previous year so that the figures for height also indicate that the field in 1941-42 was more fertile.

The sampling error increases as the crop increases in height but the increase is more during the grand period. A comparison of the growth in height of the two *rabi* crops reveals that in 1941-42 the grand period of growth commenced nearly a week earlier than in the previous year.

Earheads. With the end of the grand period of growth, when the crop was 64 days old, earheads were observed to emerge and the number went on increasing till a maximum number of 8·51 was reached on the day of harvest. The sampling error increased with increase in the number of earheads per metre and as many as 96·8 per cent of the shoots had put forth ears before harvest as compared to 88·6 per cent in the previous year. The mean number of ears per metre was higher while the sampling errors were lower than in the previous year.

From a comparative study of the results of 1940-41 and 1941-42 *rabi* seasons the following general inferences may be drawn :

(1) The *rabi jowar* crop of 1941-42 produced more shoots, plants and ears per metre and leaves per shoot as well as a greater shoot to plant ratio and was also taller than the previous year's crop.

(2) The percentage sampling errors for all these characters were lower for the crop of 1941-42.

(3) The grand period of growth was shorter and earlier for *rabi jowar* crop of 1941-42 and was better defined.

As has already been explained all these findings go to confirm the view expressed above that the soil was better and more homogeneous in the year 1941-42.

From the precision study of *kharif jowar* for a season and *rabi jowar* for the two seasons we find that the life-history of the *jowar* crop can be divided into the following distinct phases :

(*a*) Germination, (*b*) tillering, (*c*) elongation, and (*d*) reproduction.

(*a*) The period of germination extends over about 12 days as seen in the case of *kharif jowar*.

(*b*) The period of tillering begins soon after germination is complete and lasts from 24 days to about 40 days after sowing.

(*c*) After tillering has reached the maximum value, the crop enters the period of rapid elongation, also known as ' the grand period of growth '.

During the period lasting from about 45 days to about 70 days after sowing the crop grows in height very rapidly.

(*d*) Vegetative growth is almost over by the end of the grand period of growth and then begins the reproductive phase. This is marked by the emergence of earheads and with the conclusion of this period resulting in the formation of grain, the life-history of the crop is brought to a close. This period lasts from about 70 days to 125 days after sowing when the crop is harvested.

TABLE VII

Heights from sampling and photography

Days after sowing	Date	Height in cm. by		Difference in cm.
		Sampling	Photography	
35 . .	28 Oct. 1940	17·7	20·0	2·3
43 . .	5 Nov. ,,	28·1	30·0	1·9
53 . .	15 ,, ,,	45·9	45·0	0·9
60 . .	22 ,, ,,	62·7	60·0	2·7
72 . .	4 Dec. ,,	110·6	112·0	1·4
80 . .	12 ,, ,,	125·3	125·0	0·3
89 . .	21 ,, ,,	134·8	135·0	0·2

Photographic estimation of height

In the year 1940-41 an attempt was made to study the height of the *rabi* crop photographically. A long pole graduated into 15 cm. lengths, painted black and white alternatively, was placed vertically inside the field. From a fixed distance photographs of the crop with the graduated pole inside were taken on different days and the mean height of the crop on the different days was estimated from the negative. Plate XVII shows a print of the photograph taken on 22 November 1940 and Table VII gives the values of height estimated by sampling along with those obtained from the photographs. It is seen that the mean heights of plants as estimated photographically compare very satisfactorily with those estimated by sampling all the differences except the first being within the limits of the 5 per cent values of their sampling errors.

HARVESTING EXPERIMENTS

Estimation of yield by sampling. Tables VIII and IX give the estimated and actual yields of grain and total weight of straw and grain together with the percentage error in estimation and the percentage sampling error of the mean for the year 1940-41 and 1941-42 respectively. It is interesting to see that most of the percentage errors in estimation are lower than the percentage sampling errors, indicating that because of the high variability of the crop in grain yields, the errors of estimation are not significant. Perhaps a higher percentage of such a highly variable crop should be sampled so as to get more accurate estimates of the total yield. Two reasons for this high variability in the yield are (*i*) the crop is a tall one with uneven plant population and (*ii*) the soil is rather heterogeneous.

From Tables VIII and IX it appears that estimates of grain yields alone are not good for both the years as compared to the estimates of total weight which are highly satisfactory giving very low percentage of error in estimation. This. suggests that the setting of grain was not uniform- There was not much difference in the results obtained by the linear and the parallel methods.

TABLE VIII

Estimated and actual plot yields of grain and total plant weight, percentage sampling error and error in estimation for rabi jowar, *1940-41*

Particulars	Estimated plot yields												Actual plot yields		Remarks
	By linear method						By parallel method								
	Grains			Total plant			Grains			Total plant			Grains in lb.	Total plants in lb.	
	In lb.	Per cent E. E.	Per cent S. E.	In lb.	Per cent E. E.	Per cent S. E.	In lb.	Per cent E. E.	Per cent S. E.	In lb.	Per cent E. E.	Per cent S. E.			
N. W. Plot	96·51	12·54	13·076	840·2	—2·86	11·284	106·48	24·17	12·902	915·5	5·78	10·439	85·75	865·0	Less fertile plot
S. W. Plot	115·55	10·63	13·076	830·5	3·88	11·284	105·66	1·16	12·902	776·0	—2·94	10·439	104·45	799·5	
Total .	212·06	11·49	9·246	1670·7	0·004	7·979	212·14	11·53	9·123	1691·5	0·016	7·381	190·20	1664·5	

Per cent E. E. = Percentage error in estimation $= \frac{\text{Estimated yield—Actual yield}}{\text{Actual yield}} \times 100$

Per cent S. E. = Percentage sampling error

TABLE IX

Estimated and actual plot yields of grain and total plant weight, percentage sampling error and error in estimation for rabi jowar, *1941-42*

Particulars	Estimated plot yields												Actual plot yields		Remarks
	By linear method						By parallel method								
	Grains			Total plant			Grains			Total plant			Grains in lb.	Total plants in lb.	
	In lb.	Per cent E. E.	Per cent S. E.	In lb.	Per cent E. E.	Per cent S. E.	In lb.	Per cent E. E.	Per cent S. E.	In lb.	Per cent E. E.	Per cent S. E.			
Northern plot	70·35	13·47	30·440	1083	5·09	9·469	64·18	3·51	21·402	1040	0·94	8·869	62·00	1031	Better field
Southern plot	20·40	—32·51	30·440	1266	—8·79	9·469	17·40	—42·48	21·402	1241	—10·62	8·869	30·25	1388	
Total	90·75	—1·63	21·524	2349	—2·89	6·696	81·58	—11·57	15·134	2281	—5·69	6·272	92·25	2419	

Per cent E. E. = Percentage error in estimation = $\frac{\text{Estimated yield} - \text{Actual yield}}{\text{Actual yield}} \times 100$

Per cent S. E. = Percentage sampling error

TABLE X

Analysis of variance, mean weight per metre, S. E. and C. V. for both the years rabi jowar

Factors	Degrees of freedom	For *rabi jowar* 1940-41				For *rabi jowar* 1941-42				Remarks
		Grain weight in gm.		Total plant weight in oz.		Grain weight in gm.		Total plant weight in oz.		
		Linear	Parallel	Linear	Parallel	Linear	Parallel	Linear	Parallel	
Plots	1	2142·5	4·05	0·7	138·1	14761·4	12949·0	245·9	295·5	Plot variance, rather high for 1941-42 *rabi jowar*
Between samples	38	** 2529·4	** 2219·8	** 130·5	* 114·8	** 2256·4	* 901·8	** 181·7	* 150·3	
Within samples	40	935·9	1015·1	46·8	60·4	626·0	541·6	76·0	91·1	
Total	79	1717·7	1581·7	86·5	87·6	1589·2	871·9	129·0	122·2	
Mean and the S. E. of mean		57·65 ±5·62	57·67 ±5·27	16·01 ±1·28	16·23 ±1·20	24·67 ±5·31	22·19 ±3·36	22·5 ±1·51	21·9 ±1·37	
C. V. per cent		87·2	81·6	71·37	66·02	192·52	135·36	59·89	56·09	

S. E. = The sampling error of the mean
C. V. = The coefficient of variation per metre
* = Significant at 5 per cent level
** = Significant at 1 per cent level

Table X, giving the analysis of variance for both the years, indicates that the total variance and sampling error by parallel method is lower than by linear method especially for grain weight. This inference is well brought out by the coefficient of variation. The mean values of grain and total plant obtained by the two methods of sampling are of the same order of magnitude so far as the totals of the two plots are concerned. These two methods were tried just before harvest to estimate the growth of the crop and the analysis of variance is given in Table XI. The parallel method is better than the linear method for all plant attributes except height. Neither of the two methods tried is quite satisfactory for estimating the height since the correlation between the two ultimate units of the same sample has not been removed by taking the units parallel instead of in a line.§ This point requires further examination.

It is to be noted that the crop of 1940-41 has yielded a larger amount of grain than the crop of 1941-42 in spite of much better growth and greater number of ears and also higher total weight in the latter year. The reason for this is to be found in the meteorological conditions prevailing during the grain-setting period. This aspect is examined in detail and will be discussed later.

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§A three-tined country drill had been used in sowing so that the positive correlation for the parallel method also is perhaps understandable, as there is a higher probability of the two neighbouring metre lengths having been sown simultaneously than at different times during the movement of the drill along the rows.

Estimation from plant attributes. It is believed that the plant attributes quantitatively measured should be able to provide an estimate of the yield of crop. The growth of plants like *jowar* with a straight and non-branching stem can be morphologically studied by measuring the girth and height of the plant as well as the leaf area. An attempt was made to find out how far the girth and height measurements made 15 days before harvest are correlated with the yield of straw and grain. The method followed has already been described under 'Materials and methods.'

TABLE XI

Analysis of variance by linear and parallel method on the days of harvest

Date			20 January 1941				24 January 1942							
Plant character			No. of shoots		No. of ears		No. of shoots		No. of plants		Height in cm.		No. of ears	
Factor	Sample shape	D. F.	Linear	Parallel	Linear	Parallel	Linear	Parallel	Linear	Parallel	Linear	Parallel	Linear	Parallel
Plots . . .		1	532·5	163·7	12·8	96·8	7·8	37·8	0·3	0·8	12,214·1	10,351·2	17·1	28·4
Between samples .		38	30·5*	23·6	22·5*	16·9	26·3*	26·3	8·0	4·2	3,400·9**	2,767·4**	27·6	20·3
Within samples .		40	14·8	17·6	8·5	12·6	15·2	26·6	5·1	4·7	654·7	817·3	16·4	24·3
Total .		79	28·9	22·3	15·3	15·7	20·6	26·6	6·4	4·4	2,122·0	1,876·0	21·8	22·4
Mean value and the S. E. of the mean			6·91± 0·617	7·17± 0·543	6·13± 0·529	6·20± 0·459	8·79± 0·570	9·29± 0·570	5·66± 0·317	5·50± 0·299	182·2± 4·61	181·5± 4·16	8·51± 0·588	8·73± 0·504
Coefficient of variation (per cent) .			80·0	67·7	77·1	66·3	58·4	55·2	50·0	37·3	32·0	29·0	61·8	51·7

* = Significant at 5 per cent level
** = Significant at 1 per cent level

Total yield (grain+straw)

The correlation coefficients between the different factors are given in Table XII together with their standard errors.

TABLE XII

Coefficient of correlation between height, girth, total plant weight and weight of grain

Factors	Correlation coefficient	Standard error of $\gamma = \frac{1-\gamma^2}{\sqrt{n-2}}$
1 Height and girth . .	+0·9286§	±0·0357
2 Height and weight of plant.	+0·8522§	±0·0503
3 Height and weight of grain	+0·7728§	±0·0511
4 Girth and weight of plant .	+0·9113§	±0·0396
5 Girth and weight of grain .	+0·8357§	±0·0528
6 Weight of plant and weight of grain	+0·8236§	±0·0546

§Significant at 1 per cent level

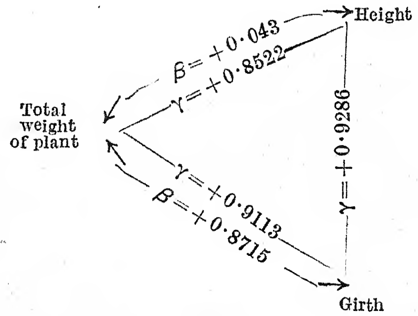
The normal equations treating yield as an independent variate were solved by the method indicated by Snedecor [1938].

The β values are

$$\beta y_{1\cdot2} = +0\cdot0436$$
$$\beta y_{2\cdot1} = +0\cdot8715$$

where y stands for total weight of plant, 1 for height and 2 for girth.

The following is the schematic representation of the Υ's and β's.



The multiple correlation R between plant weight, girth and height is found to be as high as 0·9117 and is highly significant. The value of the multiple correlation is of the same order as the correlation between girth and total weight (0·9113) indicating thereby that by taking

into consideration the height factor we obtain no additional information.

All the correlations between the four factors shown in Table XII are highly significant. So the factors are inter-related with each other to a great extent.

Yield of grain. The β values for grain weight are

$$\beta_{1y \cdot 23} = -0 \cdot 0394 \pm 0 \cdot 1383$$
$$\beta_{2y \cdot 13} = +0 \cdot 5376 \pm 0 \cdot 1757$$
and $$\beta_{3y \cdot 12} = +0 \cdot 3673 \pm 0 \cdot 1246$$

where 1, 2, 3 and y stand for height, girth, total weight and weight of grain respectively. Regression coefficient's t values are 0·2840, 3·0596 and 2·9474. The first β value is not significant while those for girth and total weight shows high significance when tested by t value. Of these two, girth is more important than total weight.

The value of R the multiple correlation works out to be 0·8493 and is significant at 1 per cent level. The equation relating yield to other factors is as follows :

$$\Upsilon = -17 \cdot 6087 - 0 \cdot 001143x_1 + 00 \cdot 7872x_2 + 0 \cdot 0003626x_3.$$

where Υ is weight of grains in gm., x_1 and x_2 are height and girth respectively in cm. and x_3 is the total weight in oz.

The possible sources of error in this experiment are the following:

(1) Errors in measurements,

(2) Cutting of plants at different heights above the ground,

(3) Loss of some leaves,

(4) All the plants might not have dried to the same extent before weighing,

(5) Some ears are barren and grain might have been lost during harvesting or threshing, and

(6) errors in random selection.

In spite of these possibilities, a study of the correlations between yield of grain, height, girth and total weight has given very satisfactory results indicating the possibility of predicting the yield of grain from girth measurement made about a month before harvest, provided the setting is normal. The shrinkage in grain weight expressed as a percentage of the weight of grains at harvest from these selected plants was found to be 20·25.

(*c*) *Estimation of the yield of total weight by plant attributes obtained from samples.* The correlations between height, number of shoots and weight of shoots per sample by linear and parallel method of sampling were found to be the following :

Correlation coefficient r	Linear method	Parallel method
r_{12}	+0·1503	—0·1940
r_{13}	+0·6000	+0·5534
r_{23}	+0·6408	+0·3453

where 1, 2 and 3 stands for mean height, number of shoots and total weight of samples respectively.

The value of r_{12} is low and not significant in both the cases thus suggesting that height is independent of the number of shoots per sample. Greater height as also higher number of shoots per sample have given rise to greater weight of the sample.

The regression coefficients and multiple correlation are as follows :

	Linear	Parallel
$\beta_{13 \cdot 2}$	0·5153	0·6447
$\beta_{23 \cdot 1}$	0·5633	0·3700
R	0·8186	0·6961

We find that both the factors, height and number of shoots contribute fairly equally to the estimation of total plant weight by linear method while mean height per sample appears to exert greater influence on the total plant weight by parallel method. The multiple correlation coefficient R is highly significant ; a better estimate of R is obtained by the linear method.

YIELDS OF 1940-41 AND 1941-42

In spite of the much more luxuriant vegetative development in the year 1941-42, the yield of grain was poorer than in 1940-41. The reason for this became obvious on a closer examination of the earheads. It was found that some ear heads were full of grains while others had no grains at all. In between these two types there were ear heads with various degrees of grain setting. Thus the very poor yield of grain in 1941-42 was clearly due to the partial failure of pollination and fertilization. The weather conditions associated with this partial failure of grain formation are briefly described below. The flowers open mostly between 12 midnight and 4 in the morning. So evidently the weather at night may be expected to play an important part in pollination and fertilization. The wind velocity, air temperature and vapour pressure at the epoch of minimum temperature were examined in this connection.

Tables XIII and XIV show in sequence the percentage of total ear number that were out of leaf sheath between the respective dates in each plot as well as in both the plots, together with the mean maximum and minimum temperatures, wind velocity and vapour pressure at minimum temprature epoch for the years 1940-41 and 1941-42 respectively.

As we have data only for a couple of years it is possible to make only a qualitative comparison of the main features revealed by Tables XIII and XIV.

TABLE XIII

Meteorological elements and percentage ear emergence for rabi *crop of 1940-41*

Particulars	Percentage of ear emergence			Actual yield of grains in lb.
	Between 25-11-40 and 12-12-40	Between 13-12-40 and 21-12-40	Between 22-12-40 and 20-1-41	
N. W. Plot	63·0	6·5	30·5	85·75
S. W. Plot	60·7	18·5	20·8	104·45
Total	62·0	11·8	26·2	190·20
Mean maximum temperature in °C.	30·1	28·0	27·8	..
Mean minimum temperature in °C.	16·4	11·9	10·1	..
Mean daily wind velocity in miles per hour	3·1	4·0	1·9	..
Mean vapour pressure at minimum temperature epoch	12·8	9·1	7·7	..

TABLE XIV

Meteorological elements and percentage of ear emergence for rabi *crop of 1941-1942*

Particulars	Percentage of ear emergence			Actual yield of grain, in lb.	Remarks
	Between 17-11-41 and 5-12-41	Between 6-12-41 and 24-12-41	Between 6-12-41 and 24-1-42		
N. Plot	55·5	22·1	44·5	62·00	Due to lodging on 24-12-41 only N. Plot was sampled
S. Plot	63·8	..	36·2	30·25	
Total	59·4	..	40·1	92·25	
Mean maximum temperature in °C.	30·8	31·8	30·1	..	
Mean minimum temperature in °C.	12·1	18·5	13·9	..	
Mean daily wind velocity in miles per hour	2·1	1·9	2·2	..	
Mean vapour pressure at minimum temperature epoch	8·5	9·8	8·3	..	

It will be seen from the above tables that about 60 per cent of the ears emerged during the first period, viz. 25 November 1940 to 12 December 1940 in the first year and 17 November 1941 to 5 December 1941 in the second year. The maximum temperatures are more or less similar. The main differences lie in the minimum temperatures and mean wind velocity during the first period (period of maximum ear emergence). In the second year the minimum temperatures are much lower than those in the previous year, the difference being of the order of 4·3°C. during the critical period (maximum ear emergence). At the same time the wind velocity is also smaller in the second year. It may be pointed out that a suitable temperature is necessary for opening of the flowers and sufficient agitation by wind is of great importance for effecting pollination. These conditions appear to have been more favourable in the first year. It is also significant that in the second year the air was much drier during the critical period than in the first year. This might have also influenced adversely the viability of the pollen grains. The daily values of the minimum temperatures, wind velocity and vapour pressure during the two years are plotted in Fig. 4.

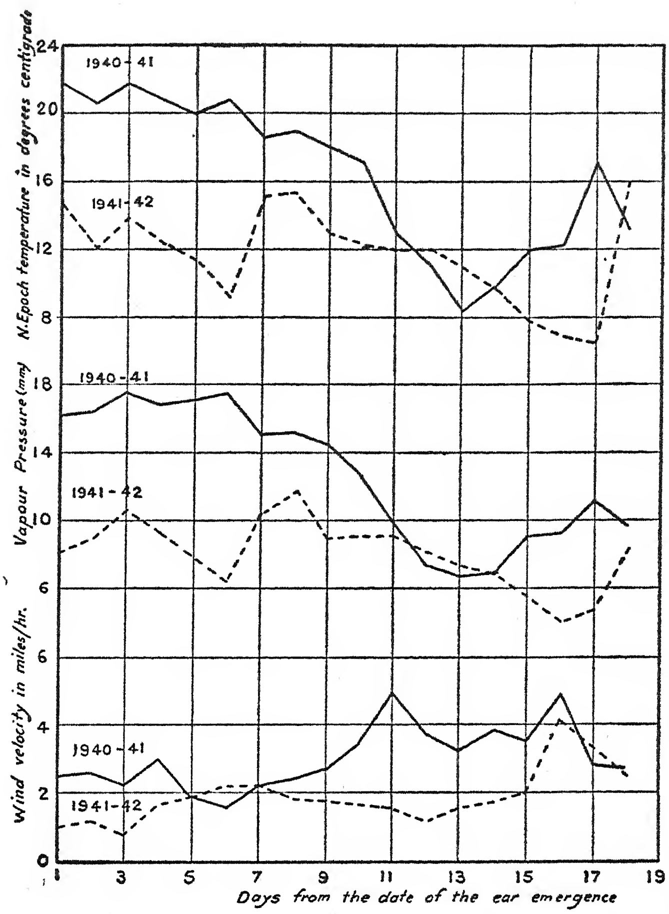


FIG. 4. Variation of minimum temperature, vapour pressure and wind velocity during 18 days after emergence of ears in *rabi jowar*

CONCLUSION

Two shapes of 2 metre sample designated as linear and parallel have been tried. During the course of analysis it is seen that in the parallel method the correlation between the ultimate units of the sample has been reduced generally, showing that this method is the better. For further improvement the following two shapes of the sampling unit where the ultimate units have been separated more widely from each other will be tried in the near future.

(1) *Linear method.* The individual metres of the sample to be separated by one metre instead of half a metre. The sampling rod will be as shown below:

Count	Omit	Count
1 metre	1 metre	1 metre

(2) *Parallel method.* Instead of taking the ultimate units from two adjacent rows, these may be taken from rows further away from each other. In the crop studied a 3-tined drill was used for sowing. Therefore for this particular case the individual metres may be so distributed that both the metres are not taken from rows sown at the same time. Thus the shape of the sample will be as shown below:

Sown together { ....1 metre / .... / ....
Sown together { ....1 metre / .... / ....
} under observation

We found that the meteorological factors such as wind velocity, minimum temperature and vapour pressure exert a profound influence on the setting of the grains. In spite of good growth, the yield of grain may be much reduced if during the period of setting the climatic factors are quite adverse. The optimum values of temperature, wind velocity, etc. during blooming period have to be determined to throw further light on this aspect of the

problem. When the data are collected for a sufficiently large series of years, it will be possible to establish crop weather relationships precisely.

Acknowledgements

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PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN CANAL TRACT

V. WATER REQUIREMENT

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(With Plate XVIII and five text-figures)

General

The problem

The Deccan Canal tract is characterized by a very precarious rainfall which causes occasional severe famines; but due to the favourable geographical position of a range of mountains bordering on its western frontier, where rainfall is not only excessive but assured—ranging from 100 to 200 in.—Government naturally turned its attention to making some of this water available for irrigation; and the first of a series of perennial canals—the Mutha Canal—was built in 1880, while the last—Nira Right Bank Canal—was completed in 1929. It became, however, soon apparent that as a result of the availability of water at his command for which he is assessed not by the amount used but by the area irrigated, the cultivator is apt to over-irrigate the crop. Not only has this led to a great waste of water which is brought to his door at such a high cost, but it has in addition resulted in the damage to the soil, the more obvious of which is water-logging with concomitant salt efflorescence. In this way during the last 40 years, about 35 per cent of the irrigable area of the older canals has been made unfit for cultivation and requires reclamation. Further, heavy watering brings in its trail the necessity of high manuring, which increases the cost of production, and while this tract is well known to be one of the finest sugarcane-producing tracts in the world, and with an assured supply of water, prolific crops of thick soft canes are in fact produced, the cost of production per ton of cane is found to be much higher than that of the rain-fed tracts of northern India. As, however, no systematic scientific data were available on these problems which arose with the introduction of perennial irrigation, the Bombay Department of Agriculture established a research station at Manjri in 1893 and after a great deal of field experimental work for a number of years evolved the well-known Manjri standard method (Leaflet No. 17 of 1929). It has been estimated that the improvements as recommended by this method consisting of deep ploughing by gallows plough, planting in furrows 4 to 5 ft. apart and interculturing has resulted in the saving of water by 33 per cent in the hot season and 25 per cent on the whole. Further attempts to determine the exact water requirement of sugarcane and its periodical distribution under field conditions have been rather inconclusive, and it was felt that a thorough investigation was required on the influence of the various factors operating during the life-cycle of the plant in order to elucidate this problem which is a very important one from the standpoint of the canal irrigation. This has been started with the establishment of the Sugarcane Research Scheme, Padegaon, financed jointly by the Imperial Council of Agricultural Research and the Government of Bombay and the following investigation forms the first of a series of articles in this connection.

Historical

Investigations on the exact water requirement of plants have been mainly directed to determine the ratio between the amount of water expended and the dry substance formed by the plant. The first investigation in this line has been conducted by Hellriegel [1883] who inferred a similarity in the water requirement in all the crops. This has been, however, disproved by later workers as Schroder [1895], Leather [1909, 1911], Briggs and Shantz [1914, 1917], Shantz and Piemeisal [1927], Tulaikov [1929] and Singh and Singh [1936] who found that while the crops could be divided into groups as regards their water requirement, a distinct variation among these groups could be detected. Even in cereals, Schroder [1895] distinguished two groups, the water requirement of the first group being 2·2 times that of the second. In general, the most economical plants are those of

* This scheme is partly subsidized by the Imperial Council of Agricultural Rerearch

short growing period. In the case of sugarcane, Leather [1911] has calculated the water requirement per acre to vary from 33 in. to 66 in. for the minimum and maximum production of dry weight production, while investigations by Singh and his co-workers [1935] have shown its minimum water requirement to be 45 in.

Besides the peculiarities of the plant, environmental factors—particularly meteorological conditions, soil moisture and soil fertility are found to influence the efficiency of transpiration to a great extent. An excellent historical review of the influence of these factors has been taken by Miller [1931]. Among the atmospheric factors, humidity is considered to be undoubtedly the most pre-eminent, there being great reduction in transpiration with the rise in the air humidity. The rate of transpiration increases with the rise in the water content of the soil up to a certain limit which appears to be about 70 to 80 per cent of the soil saturation. An increase above this has got no effect which is traced to the deficiency in the oxygen-supplying power of the soil. According to Singh and Singh [1936] the optimum growth of cereals may be secured at percentages between 22 to 40 while in vegetables the figure varies between 37 and 55 per cent of the water-holding capacity of the soil. Leather [1911] maintains that the concentration of water in the soil which is necessary for good development varies largely with the nature of the soil. While in Pusa soil 10 per cent moisture is sufficient for the development of good plants, in the black cotton soil 25 per cent is too small for any thing but the most meagre growth. Provided, however, the water supply does not fall below a certain concentration, the physical nature of the soil has no influence on the transpiration ratio. On the other hand, the degree of the fertility of the soil produces a considerable effect on it. It has been observed by Kiessalbach [1916] that while manuring of soil diminishes the intensity of transpiration, its effect is more strongly marked with the poor soil and only slightly with the fertile soil.

Very little information of a definite nature is available as regards the influence of the ground water level on the water requirement. Balls [1919] states that due to the proximity of water table, the cotton plant in his experiments in Egypt drew on it for a portion of its needs which resulted in the high utilization of water by the crop than what was applied in irrigation. Israelsen [1935] considers that the drainage of the Millard country land has contributed to the increase in the irrigational requirement of the crops, although it is not as great as is generally supposed. From his experience at Chakanwali in the Punjab, Taylor [1935] has suggested that in the areas with a water table of about 2 ft. below the surface, 30 per cent less water is required to mature a sugercane crop than in areas having it below 8 ft.

Factors

It would be seen from the above historical review that the important factors responsible in the transpirational loss of water are the inherent characteristics of the plant and the changes in the environment. In order to determine the influence of inherent characteristics, two varieties with divergent characteristics were included in the experimentation. POJ 2878 is an early-maturing, flowering variety, while Pundia is a very late-maturing, non-flowering one. There is also a great deal of variation in the underground behaviour of these varieties, the former being deep-rooted and the latter a shallow-rooted one. The environmental factors consist of (1) soil, (2) ground water-table, (3) meteorological conditions, (4) cultivation methods, and (5) manuring. The conditions prevailing in the experimental series are described below.

(1) *Soil.* The soil of the Deccan Canal tract falls under the broad group of *Regur* or black cotton soil. This is further classified by Basu and Sirur [1938] into distinct soil types according to the modern genetic method based on profile characteristics. According to this classification, the soil under experimentation is denominated as type 'B' and possesses the following characteristics.

This is a thoroughly leached soil, and also poor in colloid both organic and inorganic. The depth of the soil varies from $2\frac{1}{2}$ in. to 6 ft. or more and is generally underlaid with *murum* substratum. The drainage is not bad and the moisture retentive power is good. The soil is rather cloddy and as a result cultural operations are found to be beneficial in the way of proper aeration and nitrification. Farmyard manure gives a poor response in this soil but phosphatic manures have given promising results [Rege and Sannabhadti, 1943]. It is also well supplied with calcium carbonate. The moisture equivalent as obtained by Briggs and McLean method [1910] is 43·8 per cent while its wilting coefficient approaches 26·1 per cent on oven-dry basis. Some typical analytical results are given in Table I.

(2) *Ground water-table.* A number of permanent bore holes have been maintained on the farm area on the grid system in order to keep a record of fluctuations in the subsoil water level. One of these bores adjoins the land selected for water experiments and a record of weekly fluctuations in the water depth has been maintained throughout. The trend of the annual fluctuations showed that the average depth of water during the growing

period of cane was near about 9 ft. while the minimum (6 to 7 ft.) was reached somewhere in October or November after the monsoon. The soil depth in this experimental series varied from 24 in. to 48 in. with *murum* isobath. The exposure of the root system of both the varieties had shown the maximum penetration of roots to vary between 2 to 3 ft. according to the depth of the soil, there being no penetration beyond this even in the case of higher depth of soil. Special experiments laid down to determine the capillary rise through *murum* gave negative results. It would be thus quite evident that in this experimental series there has been practically no contribution from the ground water-table to the water requirement of the crop.

(3) *Meteorological conditions.* A well-equipped meteorological observatory has been set up on the farm where day-to-day observations are being maintained in order to determine their influence on the developmental behaviour of the crop. The data for a few important factors are given in Table II for the first series of experiments described in sections I and II. The climate is mainly sub-tropical with well-defined rainy and dry seasons, extreme temperatures of the year being between 36° and 45°F. as minimum occurring during the months of December and January and

TABLE I

Some analytical figures of soil type 'B' according to its profile characteristics

Depth (in.)	$CaCO_2$ per cent	*p*H	Exch. Ca. m.e. per cent	Exch. Mg. m.e. per cent	Exch. K m.e. per cent	Exch. Na m.e. per cent	Humus per cent	Total N per cent	Total P_2O_5 per cent	Total K_2O per cent
0-9	9·61	8·79	26·25	10·42	1·97	4·08	0·95	0·048	0·042	0·313
9-20	8·87	8·31	30·89	9·88	2·64	4·40	0·27	0·044	0·113	0·606
20-26	11·74	8·41	22·00	13·75	3·44	9·79	0·19	0·039	0·126	0·380
26-32	13·87	8·57	30·50	18·23	3·76	11·34	0·31	0·038	0·130	0·410
32-38	10·49	8·57	28·78	12·30	1·45	11·54	0·19	0·036	0·124	0·440
38-44	12·03	8·54	44·50	15·09	3·36	11·28	0·17	0·033	0·138	0·411

TABLE II

Monthly averages of some important meteorological factors

Month	1933					1934					1935				
	Rain-fall in inches	Temperature °F.		Humidity per cent at		Rain-fall in inches	Temperature °F.		Humidity per cent at		Rainfall in inches	Temperature °F.		Humidity per cent at	
		Max.	Min.	8 a.m.	3 p.m.		Max.	Min.	8 a.m.	3 p.m.		Max.	Min.	8 am.	3 p.m.
January .	0·00	88·0	52·5	65·8	...	0·00	84·1	50·0	81·1	39·1	0·00	83·8	51·1	67·9	30·5
February .	0·00	94·3	56·4	63·5	...	0·00	97·1	51·7	66·8	22·9	0·00	91·0	51·7	59·9	14·5
March .	0·18 (2)	100·0	62·4	54·3	...	0·18 (1)	96·4	59·2	53·3	19·5	0·00	95·3	57·6	43·4	12·8
April . .	0·00	101·1	69·6	45·9	18·0	0·66 (3)	103·2	69·5	57·6	19·4	0·00	98·9	66·4	52·1	15·0
May . .	0·94 (5)	97·2	72·5	68·8	38·2	1·27 (2)	102·2	70·8	51·2	16·9	0·00	102·6	72·1	48·1	16·9
June . .	2·74 (13)	88·1	71·9	77·3	56·8	4·57 (10)	90·9	71·7	73·0	76·7	2·66 (10)	91·9	69·7	75·8	47·2
July . .	2·61 (10)	84·9	71·4	81·9	67·3	1·84 (16)	89·2	70·8	85·9	75·0	0·90 (8)	84·6	71·9	75·8	57·5
August .	3·66 (11)	83·0	69·8	87·1	73·2	1·16 (10)	83·4	70·8	83·2	66·8	6·47 (11)	84·2	70·2	84·4	63·9
September .	4·69 (14)	85·9	68·8	85·4	70·4	2·70 (6)	84·8	68·3	81·1	56·6	1·37 (5)	84·8	67·8	83·4	53·4
October .	1·20 (11)	88·1	65·8	83·4	44·5	4·06 (7)	88·4	65·7	75·7	38·5	6·60 (14)	87·3	67·9	82·5	51·5
November .	1·07 (5)	86·4	61·3	74·4	34·8	5·57 (3)	82·1	52·6	82·3	45·3	0·00	85·5	53·6	79·0	30·0
December .	0·75 (2)	82·6	71·1	69·4	36·6	0·00	82·3	48·9	75·6	40·1	0·36 (1)	84·6	52·0	77·3	31·5
Total .	17·93 (69)	...	...	...	...	21·01 (58)	...	...	...	...	18·36 (49)	...	...	...	...

Figures in brackets indicate the number of rainy days

between 105° and 110°F. as maximum during April and May. The growth of the plant practically ceases when these conditions occur, but tillering is not much affected. With the onset of monsoon, there is a rapid drop in the maximum temperature which remains fairly constant at about 86°F. when the diurnal range is also at its minimum (14°F.). In the case of sugarcane, this period coincides with the grand period of growth and from the standpoint of temperatures approximates the optimum conditions. It would be further evident from the table that while the temperature fluctuations from year to year are the least during the growth period, the distribution of rainfall as well as humidity are extremely variable. Although from the standpoint of total rainfall these three seasons do not show wide variation, the records of the last 14 years have shown such wide fluctuation as 9 to 33 in. The average rainfall is about 19 in. and this is not only not sufficient but is precarious and from the standpoint of dry farming, the cultivation of even short-term crops as *jowar* or *bajri* is purely a gamble. With the introduction of canal irrigation, the importance of rainfall is minimized and crops like sugarcane are grown with security. It has been, however, found from other experimental data that in spite of controlled conditions of irrigation and manuring, other climatic factors—specially humidity—do play an important part in the plant development. An analysis of the data collected for six years has shown a correlation of growth with humidity which is found to be significant at 0·01 level for five years in the case of Pundia and for three years in the case of POJ 2878. This is also well illustrated in Fig. 1 where mean temperatures and humidity

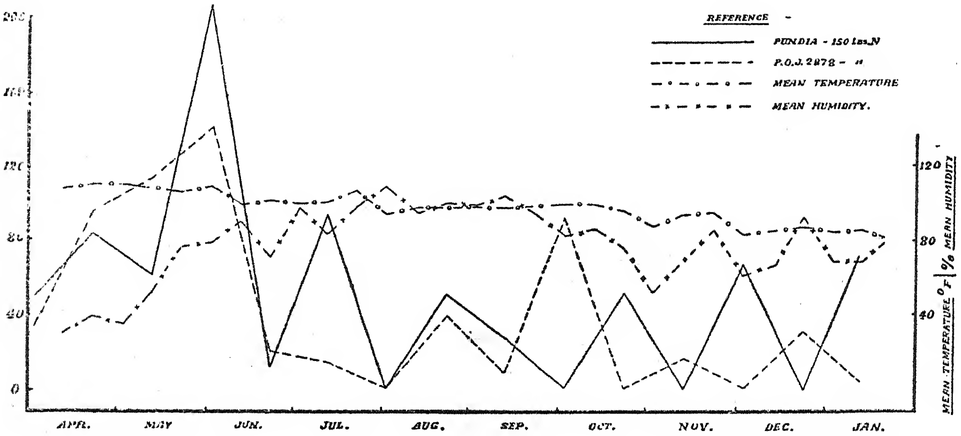
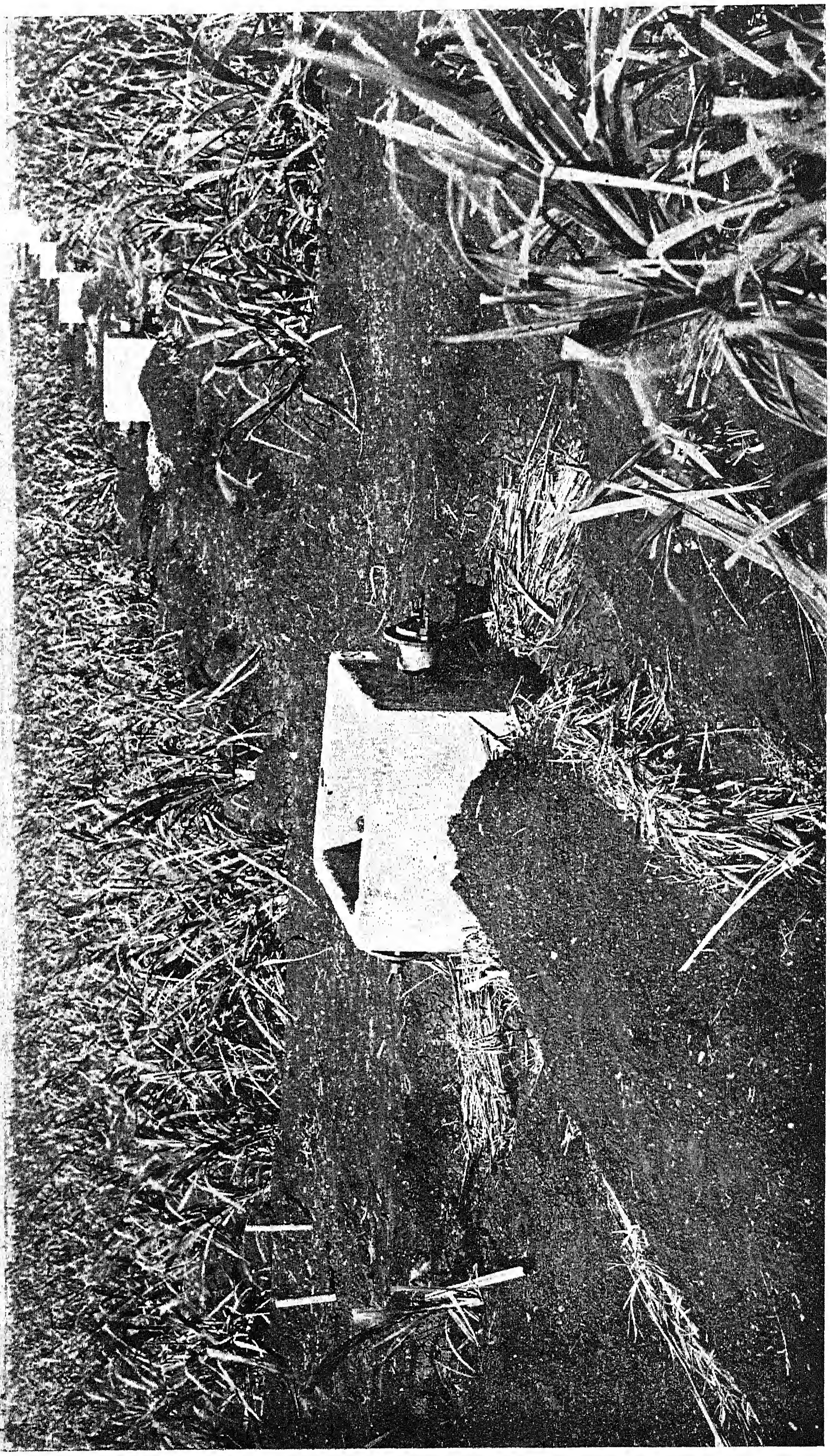


FIG. 1. Periodical increase in dry weight corrected with atmospheric factors—1933-34

are represented in relation to the increase in weight of two varieties calculated by the Blackman's formulae. It clearly brings out the varietal characteristic, Pundia being more susceptible to changes in the humidity than POJ 2878. Some of the new Coimbatore varieties as Co 419, Co 360, Co 413 have been found to be even more indifferent to climatic fluctuations than POJ 2878. The detailed analysis of the climatic relationship will be dealt with in a separate paper; but it can be definitely said in general that the humid oppressive climate precursory to rain is the ideal condition for growth of sugarcane and during those seasons such days are many, the crop yields are the best. It would be thus quite evident that besides its direct influence on the rate of transpiration, atmospheric humidity would also play an important part in determining the efficiency of water requirement of sugarcane by affecting its growth. It has been, however, observed that the deleterious effect of its deficiency under natural conditions is modified to some extent by the capacity of the crop to create its own humidity due to periodic irrigation, once the crop has attained its full tillering and sufficient height to prevent the free movement of wind which attains a high velocity in this tract. About 4 to 12 per cent higher humidity is prevalent inside the crop than outside, depending upon the size of the block, and the higher figure has been found to be more common on the developed canals where both due to growth of trees and larger area under cane, the velocity of wind is controlled to a greater extent. The absence of great variability in yields and the better performance of the susceptible varieties like Pundia and E K 28 on these developed canals would be thus quite explicable. The site for these experiments was, however, specially selected on a new canal where the environmental conditions would be more exacting, so that the results on the minimum water requirement could be recommended with assurance to any place in this tract.



Water distributing tanks showing outlets on both sides for letting out water to plots on both sides with flap arrangement for letting out water. The tanks are connected by 4 in. hume pipes underground through which the water measured by the meters flows

(4) *Cultivation methods.* These had received a very careful investigation at Manjri and the methods evolved there have been followed in toto in these experimental series. These consist of deep ploughing by Gallows plough, planting in furrows 4 ft. apart, slow irrigation, interculturing a few times till the crop makes sufficient growth and earthing up when two or three internodes are formed on the surface. The number of setts required for planting were fixed as 10,000 three-budded setts per acre.

(5) *Manuring.* Manuring of sugarcane has been found to be quite essential in this tract and consists chiefly of basal sunn green manuring or a heavy dose of farmyard manure if available and nitrogenous top-dressings of both sulphate of ammonia and oil cakes. While the standard Manjri method has recommended 150 lb. N as a suitable quantity, doses from 300 to 400 lb. N are not uncommon.

Outline of the scheme of work

The problem of the water requirement in the case of sugarcane is complicated by the fact that the crop is irrigated throughout its life-cycle at short intervals and is further heavily manured with nitrogenous top-dressings and the investigations must necessarily comprise a close study of the interrelationship of water and manure. A comprehensive programme has, therefore, been outlined to find out (1) the minimum delta to raise a normal crop with a view to spread the available canal water on the maximum acreage, (2) the suitable combination of water and manure to secure the maximum yield per acre, (3) the periodic distribution of the total delta in order to utilize it to the best advantage, and (4) the variable behaviour of the soil types.

These quantitative studies are mainly carried out in the field and differ in this respect from the standard method of pot culture. The latter method is no doubt capable of greater accuracy ; but for the same reason it has to be conducted under conditions which do not approach to the field practices. It is, for instance, necessary to transfer the soil to the pots thus disturbing the profile characteristics, which according to the modern genetic conception of soil classification give a true index of the soil type. The most obvious difference is found in the root distribution specially in the heavier soil groups such as the black cotton soil. It has been observed that while in the field the root-system is restricted within a depth of about 36 in. the same soil when transferred to the pots shows its very free development throughout the depth of the soil (48 in.). As regards the method of irrigation, surface irrigation is the common feature in the field while sub-irrigation is essential in the pot-culture experiments. It has been estimated by Widstoe [1909] that surface irrigation entails about 60 per cent more loss by evaporation than in the case of sub-irrigation. In the case of soil moisture, wide fluctuations occurring in the field during the irrigational intervals are not permitted in the pot-culture series where the moisture is kept at a definite figure and the loss is made good either daily or on alternate days. It would be thus quite evident that these differences between the pot-culture and field practices would diversely influence the results and it is for this reason that the method of pot culture is not considered by us as quite suitable for securing practical recommendations as regards the irrigational quantities under field conditions. It has been, however, utilized, whenever necessary, to test the validity of some important findings accrued from the field studies about the influence of edaphic factors.

Very reliable data can be obtained by field experimentation if certain conditions are satisfied and the possible sources of error are avoided. One obvious cause of great inaccuracy in field experiment is the loss by percolation and absorption in the irrigational channels which has been found to vary from 22 to 40 per cent depending upon the distance of the field. This has been entirely prevented in these experiments by taking water straight to the experimental plots through underground cement pipes and distribution tanks fitted with quick opening outlets (Plate XVIII) the quantity of water being accurately measured by Leed's differential rotary water meters which measure water quantities to a minimum of 10 gallons. Due to the undulating topography of this tract, the plot size in the ratio of 1 : 10 as recommended for dry-farming experimentation is found to be impracticable from the standpoint of uniform distribution of irrigational water and this is therefore modified to the ratio of about 1 : 1·7, the actual size being 32 ft. × 54·45 ft. with eight rows 4 ft. apart which equals exactly four cents in area. The main experimental plot excluding the ring is 2·5 cents or 1 *guntha* and contains a population from 600 to 1000 canes. As regards the layout, a statistically replicated method of pooling together all the treatments and varieties in a complex experiment is adopted and in order to avoid the effect of adjoining treatments an additional space of 8 ft. between the individual plots is left. This was left uncropped during the first series of experiments; but as it was found to affect the growth of the crop adversely due to isolation of small plots it was cropped throughout in later series. Each series of experiments was conducted for three years in order to ascertain the effect of seasonal fluctuation. The rotation observed was also a three years' one, viz. sunn (for green manuring)—cane—*rabi jowar*. The area chosen for the layout of the experiment had graded depths varying from 2 ft. to 4 ft. from the first year block to the third year.

The first series of experiments is outlined to fix a minimum and optimum delta for the same manurial dose while in later series the inter-relationship of water and manure is investigated. Special experiments were also conducted to evaluate the different systems of irrigation and to study the effect of varying intervals and wilting on the crop growth and it is proposed to discuss all these data in a series of papers. The following sections describe only the first series of experiments dealing with the total delta.

Total delta : developmental studies

This series of experiments was designed to determine both the minimum and optimum quantity of water under the same manurial dose. As under field conditions it is essential to conduct comparative trials with some treatments below and above the delta considered to be the normal requirement of the crop, this series consisted of four water treatments, viz. 70, 95, 120 and 130 acre-inches. In fixing these, the previous investigation at Manjri has been very useful, which has suggested the normal requirement to lie somewhere near 100 in. per acre. The last treatment of 130 in. reflects the cultivator's system. A uniform 10 days irrigation turn is maintained throughout the life-cycle of the plant after the third week from planting. The manurial dose is 150 lb. N in all the treatments distributed according to the standard Manjri method. The distribution consists of 50 lb. N at three weeks after planting in the form of sulphate of ammonia alone, 50 lb. two months after planting in a mixture of sulphate of ammonia and safflower cake in equal proportions and 50 lb. at earthing in the form of cake alone. The water deltas are inclusive of total rainfall and are limited to 12 months period, additional quantity being applied later to Pundia which requires about a month more to attain its maturity. The rainfall which is an uncontrollable factor under field conditions was divided into non-effective and effective depending upon whether it was received soon after irrigation or later on. It was found that in case the irrigational quantity was sufficient to saturate the depth of soil, the rain which fell during the period of the gravitational movement of water through the soil depth, which took three days in this soil did not contribute to the soil moisture and was entirely ineffective. Further effectiveness of the rain would depend upon the loss of moisture in evo-transpiration. As a general procedure therefore any rain falling within the first five days after irrigation was added to the total delta to be received by the crop, while the rain falling later on was deducted from the water quantity of the next irrigational turn, being considered as effective. This method has been found to be conductive to crop growth specially in the higher treatments where the application of the full irrigational dose after the rainfall may have resulted in the flooding of the whole field. The layout was a simple randomized one consisting of four water treatments and two varieties with six replications.

Presentation of data

(1) *Germination.* Figures for periodical germination are given in Table III.

Table III

Germination data

(Average of all rows per replicate excluding the border rows)

Variety and treatments	1933		1934		1935	
	3 weeks	6 weeks	3 weeks	8 weeks	3 weeks	8 weeks
Pundia—						
70 in. + 150 N	8·32	32·1	6·31	40·9	6·62	61·6
95 in. + 150 N	8·04	33·6	5·03	40·3	6·75	57·7
120 in. + 150 N	8·72	32·3	8·47	41·0	6·11	58·2
130 in. + 150 N	6·79	30·8	6·44	41·0	7·06	58·4
Mean	7·97	32·2	6·56	40·8	6·66	59·0
POJ 2878—						
70 in. + 150 N	8·33	47·1	1·44	47·5	4·77	66·7
95 in. + 150 N	9·09	44·2	3·03	46·7	5·94	65·4
120 in. + 150 N	7·24	39·4	2·51	44·2	4·60	63·9
130 in. + 150 N	8·41	40·8	3·49	48·5	5·08	64·7
Mean	8·27	42·9	2·62	46·7	5·10	65·2
C. D. for significance between varieties	3·17	4·36	0·98	1·29	0·89	2·18
C. D. for significance between any two treatments	5·82	7·92	2·21	2·88	2·02	4·90

The number of setts per row was kept constant on the basis of 10,000 three-budded setts per acre and the periodical counts of germination were taken in all the plots leaving out only the two border rows per plot. Irrigation was similar in all the treatments during the first three weeks. The first dose of nitrogenous top-dressing of 50 lb. N was applied all in the form of sulphate of ammonia at three weeks with 2 in. of irrigation after which the differentiation between the water treatments followed. Planting was done by mid-January except during the first year when owing to the time taken for fitting of the irrigational pipes and tanks, it was delayed by about a month. During the first year, the land could not also receive timely ploughing due to heavy rainfall (33·3 in.) during the previous season and the construction works mentioned above ; and as a result the soil had not attained the proper tilth at the time of planting. This has caused a very poor germination in the case of Pundia in all the treatments, while in the case of POJ 2878, the deleterious effect of higher watering is visible although it is not quite significant owing to high error factor. The progressive fall in germination at six weeks with increase in watering dose is quite illustrative. The low germination in all the treatments observed during the season of 1934 is mainly due to low temperatures which prevailed soon after planting. On the other hand, temperatures during 1935 were very favourable leading to the highest germination during this season. The treatment effect is not, however, visible during both the seasons. These data of three years are a good illustration of the possible effect of soil and climate on germination as described by Rege and Wagle [1939]. They also bring out clearly that POJ 2878 has a better germinative capacity than Pundia.

(2) *Tillering and borer counts.* These were taken on two random rows per plot making up a total of 12 rows per treatment. Although monthly counts of both tillers and borer attacks are maintained till the operation of earthing up, only the figures of the maximum population and maximum borer infestation with percentage success in the case of the former are given in Table IV.

The results indicate that so far as tillering is concerned there has been no significant variation due to treatments. It depends more on the initial number of germinated buds, the lesser this number the greater the tillering. In other words there is a limit to the plant population, which a specified area can hold, and the function of tillering is circumscribed by this limitation. It would be thus evident that with a better germinative capacity of POJ 2878, the ratio of tillers to mother plants are less than in the case of Pundia. So also with higher percentage of germination during the season of 1935-36, the tillering ratio has fallen in both the varieties. The number of canes at harvest and their percentage success would give an idea of the great waste of energy by the plant which is higher in the case of Pundia than in the case of POJ 2878.

In the case of the borer attack, the varietal characteristic is also prominent, POJ 2878 being definitely less susceptible to it than Pundia. There is also an indication of an increase in the borer damage from year to year. As regards the treatments, the advantage of higher watering in reducing the infestation of borer is quite evident, the data being significant against 70 in. in the case of Pundia during all the seasons.

(3) *Growth.* This has been periodically measured directly in the field by such observation as total height, height of millable cane, number of mature and immature internodes, circumference and the number of green leaves. The methods are the same as described by Rege and Wagle [1939] previously. In order to keep the table within limited dimensions a few typical data are given with their statistical significance in Table V for the last two seasons as the first season was mainly utilized in standardizing these methods of observations.

The comparison of the data for the two years clearly brings out the influence of meteorological factors (the average figures for the same for the respective periods are also given in this table) on growth and also the water requirement of the plant. The beneficial influence of humidity on growth has already been pointed out and it is this climatic factor which has been low during the season of 1935-36 till mid-August and has adversely affected the growth in spite of a good start in germination. Although climatic conditions improved later, POJ 2878 could not make up for this initial decrease in growth due to its characteristic of early flowering and as a result the plants remained throughout poor in height as compared to the previous season. On the other hand, Pundia was helped by the high temperatures of winter months of this season which has enabled it to attain practically the same height as in the previous season.

The growth data also clearly bring out the water relationship of the plant at different periods of its life-cycle. During the early phase, i.e. till mid-August, the favourable effect of higher waterings is visible specially in POJ 2878, which is more prominent during the adverse season of 1935-36. The absence of clear indications in the case of Pundia seems to be due to the neutralizing effect of the leaching of the nutrients by higher irrigation which will naturally affect more a shallow-rooted variety like this than a deep-rooted one as POJ 2878. This favourable effect of higher waterings on the height is, however, transitory and is entirely masked by the later growth. The systematic fall

TABLE IV

Plant population and percentage borer attack

(The plant population is expressed for 10 ft. length)

(Average of two random rows per replicate, i.e. 12 per treatment)

	1933-34					1934-35					1935-36				
	Mother plants	Total population before earthing	Canes at harvest	Per cent success on 3	Per cent borer	Mother plants	Total population before earthing	Canes at harvest	Per cent success on 8	Per cent borer	Mother plants	Total population before earthing	Canes at harvest	Per cent success on 13	Per cent borer
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Pundia															
70 in.	8·3	39·4	15·7	39·8	22·1	10·8	35·4	14·96	42·3	23·1	17·1	39·1	16·8	43·7	41·2
95 in.	9·1	40·5	20·6	50·9	18·9	10·9	33·1	13·4	40·5	21·1	15·9	45·3	18·5	47·1	35·1
120 in.	9·4	44·0	21·1	48·0	14·8	10·8	34·6	12·2	35·6	19·9	16·4	45·7	17·3	42·1	22·4
130 in.	8·4	39·7	16·0	40·2	19·0	11·3	37·8	13·9	36·6	17·7	15·9	40·7	16·6	46·2	33·4
Mean	8·8	40·9	18·4	49·7	18·7	11·0	35·2	13·62	38·75	20·45	16·3	42·7	17·3	44·8	33·0
POJ 2878															
70 in.	12·2	44·2	26·0	58·9	13·7	13·1	39·1	16·8	43·0	13·1	15·5	41·4	22·2	52·1	15·1
95 in.	12·0	41·2	24·9	60·4	13·4	12·9	37·7	18·2	48·2	13·2	18·0	42·4	26·3	58·1	13·0
120 in.	10·7	44·4	24·9	56·0	12·8	12·9	39·4	18·9	48·0	13·3	18·5	42·6	24·8	53·9	12·8
130 in.	11·6	38·9	25·1	64·4	14·9	12·9	39·0	18·5	47·4	13·2	17·6	42·3	24·1	58·4	11·6
Mean	11·6	42·2	25·2	59·9	13·7	13·0	31·3	18·1	46·65	13·2	18·2	42·2	24·4	55·6	13·1
C. D. for significance between varieties	0·99	2·86	1·95	...	0·79	0·88	1·65	1·32	...	0·58	0·59	3·49	1·64	...	1·0
C. D. for significance between any two treatments	2·42	7·07	2·94	...	1·98	2·0	3·71	2·97	...	1·31	1·34	7·84	3·74	...	3·82

TABLE V

Botanical observations in relation to meteorological factors

(Average of six plants per plot, i.e. 36 plants per treatment)

Variety and treatment	Before earthing		Mid-August				Mid-October				Mid-January			
	1934	1935	1934		1935		1934		1935		1934		1935	
	Total height (in.)	Total height (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.
Pundia														
70 in.	19·3	15·8	24·8	5·2	10·4	2·4	56·1	5·3	39·1	4·0	68·4	5·0	71·4	4·5
95 in.	18·3	16·5	25·3	5·1	21·1	3·1	51·6	5·2	45·5	4·6	73·4	4·9	74·6	4·3
120 in.	20·4	19·3	25·5	4·9	20·8	2·0	55·3	4·9	50·1	4·3	71·4	4·8	81·3	4·3
130 in.	19·9	16·4	26·9	5·0	12·9	2·5	54·5	4·9	47·4	4·7	73·5	4·7	74·9	4·2
Mean	19·5	16·9	25·6	5·1	16·3	2·5	54·4	5·1	45·5	4·4	71·7	4·9	75·6	4·3
POJ 2878														
70 in.	23·4	17·3	27·8	4·7	17·5	3·2	79·0	5·2	60·6	3·5	95·4	4·3	82·1	3·3
95 in.	23·5	18·3	29·0	4·4	17·3	2·6	77·4	4·5	52·5	3·4	94·2	4·1	87·3	3·3
120 in.	26·1	22·5	30·3	4·3	25·0	3·7	78·2	4·3	69·2	3·5	92·6	3·9	87·8	3·4
130 in.	26·4	24·3	29·7	4·4	26·6	3·8	77·5	4·1	59·6	4·0	89·1	3·8	94·1	3·5
Mean	24·9	20·6	29·2	4·5	21·6	3·3	78·0	4·5	60·5	3·6	92·8	4·0	87·8	3·4
C. D. for significance between any two treatments	3·04	3·07	3·92	0·31	7·46	1·19	9·09	0·54	7·32	0·57	6·57	0·24	12·89	0·33
C. D. for significance between any two varieties	1·55	1·49	0·71	0·06	3·62	0·22	4·66	0·10	3·59	0·28	3·20	0·12	2·01	0·17

Meteorological factors	Mid-March to end of June		End of June to Mid-August		Mid-August to Mid-October		Mid-October to Mid-January	
	1934	1935	1934	1935	1934	1935	1934	1935
Max. Temperature °F.	98·7	97·9	83·8	84·3	85·6	85·9	83·4	85·7
Min. Temperature °F.	69·8	69·3	7·08	71·3	69·1	68·1	52·5	55·5
Mean humidity per cent	43·8	40·9	80·0	68·4	67·2	68·4	58·1	57·4
Wind velocity miles per hour	7·8	7·5	6·8	8·0	6·1	5·1	1·4	1·7
Evaporation cents	47·4	51·0	18·6	27·5	23·0	24·1	18·7	19·8
Rainfall in inches	5·68	2·66	2·98	0·99	5·50	11·73	7·03	3·25

in girth in the case of Pundia with increasing doses of irrigation is a clear evidence of the higher susceptibility of this variety to the leaching down of nutrients.

Simultaneous periodic determinations of leaf area and carbon assimilation by Ganos' punch method on the topmost fully developed leaf in the field have not shown any clear differentiation between the treatments and therefore the data are not presented. In the case of carbon assimilation, the only fact worth noting is the varietal characteristic, Pundia showing a higher rate of assimilation than POJ 2878. As would be shown later, this is in consonance with the figures of tonnages in these two varieties. The influence of irrigation on the root-system is already discussed in a separate paper by Rege and Wagle [1941]. It has been shown that higher watering tends to produce a superficial root-system and a fall in root weight which is more evident in the case of Pundia.

(4) *Flowering*. Among the two varieties under experiment, POJ 2878 is the only flowering variety and the data of the periodical flowering were maintained in this variety during the later two years for two random rows per replicate. The figures for both the years showed a similar trend of early flowering with higher watering although the differences were not significant. The data are not therefore given. It was further observed that in the case of 70 in. a greater number of canes escaped flowering which seems to be the reason why eventually this treatment has made up in growth and tonnage as these non-flowered canes continued to grow when the growth in higher waterings practically came to a standstill. This has, however, affected its maturity.

(5) *Internodal lengths*. These are illustrated in Fig. 2 for the season of 1935-36 only as their presentation for all the other years was not considered necessary owing to great similarity of figures from year to year. The only fluctuation

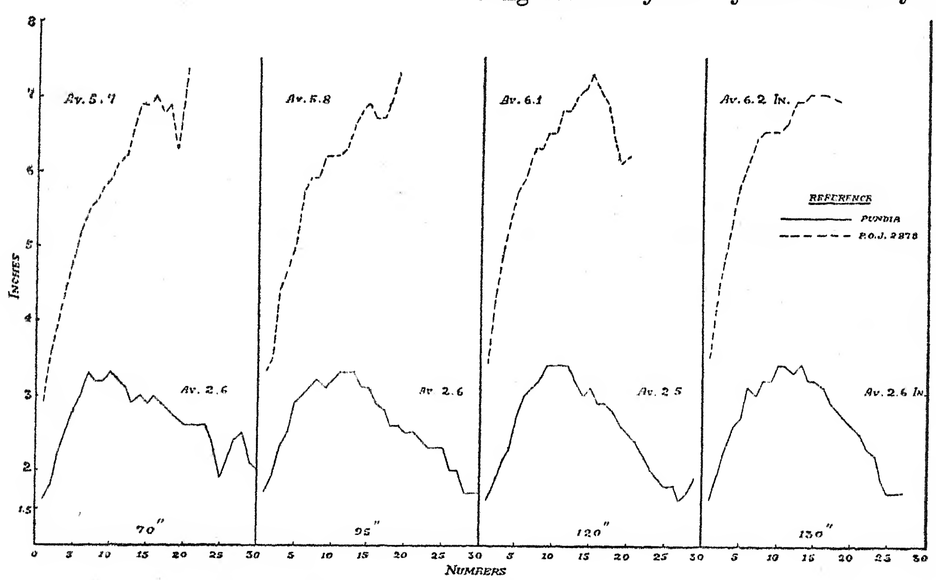


Fig. 2. Internodal lengths

observed was in the number of internodes which slightly varied from season to season. The figure clearly brings out the inherent characteristics of the two varieties, the internodal lengths as a rule being much greater in the case of POJ 2878, with the consequent fall in their number, than in Pundia. The longest internodes are, however, formed during the grand period of growth in both the varieties. Further, while in the case of POJ 2878 there has been hardly any formation of internodes after this period owing to flowering, the process continued in the case of Pundia even after this period but with the continuous fall in the length of the internodes with the progress in their number. The influence of differential waterings is clear only in POJ 2878, the average length being greater in the case of higher waterings. There are also indications of the beneficial effect of higher waterings as 120 in. and 130 in. in Pundia when one considers the formation of the longest internode. This effect seems to be, however, short-lived and the later-formed internodes get shorter in these waterings than in the lower ones perhaps due to the leaching of nutrients. This is the cause of the similarity in the average figures in the case of all the waterings.

(6) *Harvest data*. Some important data collected at the time of harvest are given in Table VI for individual years and also as an average for all the three years. During all these years

TABLE VI

Harvest data

Variety and treatment	1933						1934						1935						Average of 3 years					
	Yield of cane in tons per acre	Brix at 17·5°C.	Purity per cent	Fibre per cent	C. C. S.—tons per acre	Weight per cane in lb.	Yield of cane in tons per acre	Brix at 17·5°C.	Purity per cent	Fibre per cent	C. C. S.—tons per acre	Weight per cane in lb.	Yield of cane in tons per acre	Brix at 17·5° C.	Purity per cent	Fibre per cent	C. C. S.—tons per acre	Weight per cane in lb.	Yield of cane in tons per acre	Brix at 17·5°C.	Purity per cent	Fibre per cent.	C. C. S.—tons per acre	Weight per cane in lb.
Pundia																								
70 in. + 150N	38·7	17·53	86·1	9·44	4·19	5·02	20·4	18·17	83·7	9·80	2·17	2·82	26·0	17·17	82·2	9·16	2·73	3·24	28·3	17·94	84·0	9·47	2·95	3·70
95 in. + ,,	40·5	17·44	86·2	9·87	4·34	4·61	19·9	17·99	84·4	10·20	2·12	3·11	30·2	17·23	86·6	9·01	3·25	3·57	30·2	17·55	85·7	9·69	3·16	3·76
120 in. + ,,	43·4	17·49	84·6	9·85	4·52	4·18	13·4	17·72	86·0	9·17	1·49	2·40	27·4	17·56	86·7	9·27	3·02	3·15	28·1	17·59	85·8	9·43	3·05	3·24
130 in. + ,,	36·8	18·13	87·1	9·11	4·04	4·36	18·5	17·65	88·0	10·89	2·05	2·96	22·9	17·60	86·3	10·35	2·47	2·84	26·1	17·99	87·1	10·12	2·86	3·39
Mean .	39·8	17·65	86·0	9·57	4·27	4·54	18·1	17·88	85·5	10·01	1·96	2·82	26·6	17·39	85·4	9·45	2·87	3·20	28·2	17·77	85·7	9·68	3·00	3·52
POJ 2878																								
70 in. + 150 N	36·3	21·32	91·5	14·68	4·93	2·84	24·7	19·80	86·6	14·01	2·82	2·99	24·9	20·08	85·5	13·52	2·82	2·49	28·6	20·40	87·9	14·07	3·71	2·78
95 in. + ,,	32·8	21·89	92·3	16·28	4·54	2·69	22·4	20·49	88·4	14·06	2·78	2·55	27·7	20·92	87·9	14·88	3·45	2·49	27·6	21·10	89·5	15·17	3·47	2·58
120 in. + ,,	36·9	22·22	92·5	14·95	5·29	2·99	23·4	20·55	90·4	15·64	2·96	2·63	27·1	21·18	88·1	14·46	3·45	2·42	29·1	21·32	90·3	15·02	3·85	2·68
130 in. + ,,	29·3	22·48	93·6	14·54	4·36	2·64	20·9	20·65	90·0	13·68	2·71	2·47	25·7	21·77	88·6	16·14	3·32	2·35	25·3	21·63	90·7	15·45	3·44	2·3
Mean .	33·8	21·98	92·5	15·11	4·78	2·79	22·8	20·37	88·8	14·35	2·82	2·66	26·3	21·00	87·5	14·75	3·26	2·46	27·7	21·11	89·6	14·93	3·62	2·6
C. D. for significance between any two varieties	2·4	0·089	...	...	...	0·26	2·40	0·49	...	...	...	0·27	2·1	0·79	...	...	...	0·22	1·50	0.456	...	...	...	0·25
C. D. for significance between any two treatments	6·9	0·162	...	...	...	0·42	5·20	0·87	...		...	0·48	4·7	1·43	...	...	...	0·39	3·2	0·821	...	...	...	0·43

POJ 2878 was harvested 12 months after planting and Pundia a month later as the latter was a late-maturing variety. In the case of cane tonnages a deleterious effect of 130 in. is visible throughout the period of experimentaton in both the varieties and although this has not been significant every year, the average figures for the three years of experimentation have brought it out clearly when the seasonal effect is excluded. As regards the other treatments, fluctuations in tonnages are negligible except in the treatment of 120 in. during the season of 1934-35 in which significantly low yields are obtained for Pundia. This is, however, traced to the lying of the majority of plots in this treatment on the western border of the block where the growth was generally poor owing to the deleterious effect of the wind. The weight per cane also shows in general a progressive fall with increased waterings. From the standpoint of brix and purity, the treatment of 130 in. comes out the best followed by those of 120 in. and 95 in. while the treatment of 70 in. has shown a definite delay in maturity. In spite of this higher brix and purity, the figures for either commercial cane sugar as calculated by Srivastava's formulae or of *gul* (Table VII) reveal a definite inferiority of 130 in. There is also a distinct evidence of the increase in the fibre content in the case of 130 in. for both the varieties. It would be thus evident that there is a progressive rise in brix and purity with increased waterings which is quite distinct in the case of 130 in. as against 70 in. while the cane tonnages show the reverse order in these two treatments. As would be shown in section II, this is found to be mainly due to leaching down of assimilable nitrogen and lowering of the microbiological activity by such heavy irrigation as given in 130 in. clearly bringing out the necessity of higher nitrogenous top-dressings with such high irrigation.

(7) *Quality of* gul. Samples of *gul* were analyzed during the season of 1935-36 in order to determine the causes of the variable colour of *gul* in the different treatments. As a rule, *gul* of POJ 2878 is darker in colour than that of Pundia and when judged by the colour standards is generally inferior to it. It is, however, harder and does not rapidly sweat in the humid climate. Some of the analytical figures are given in Table VII. There is a definite indication of the fall in glucose, ash, amide N and total nitrogen with increasing quantities of irrigation. In the case of mineral constituents the results are not consistent; but in general Pundia contains less of ash and a greater quantity of it is in the form of silica than is the case with POJ 2878. The better colour of *gul* seems to be thus related to low ash

TABLE VII

Data of gul *analysis and its valuation*

Variety and treatment	Ash per cent	Ash insoluble in HCl per cent of the total	Glucose per cent	Amide N per cent	Total N per cent	K_2O per cent	P_2O_5 per cent	CaO per cent	MgO per cent	Na_2O per cent	Colour standards by tintometer readings	*Gul* tons per acre—Average of 3 years	Commercial value—Average of 3 years	Profit
													Rs.	Rs.
Pundia														
70 in.	2·67	15·15	28·79	0·0100	0·107	0·95	0·046	0·167	0·033	0·045	4	3·13	321·23	36·30
95 in.	2·25	10·34	28·79	0·0064	0·077	1·18	0·210	0·198	0·676	0·173	3	3·24	362·75	59·38
120 in.	1·93	9·00	24·38	0·0040	0·044	0·56	0·225	0·176	0·090	0·106	2	2·92	326·92	16·96
130 in.	1·59	4·77	25·72	0·0027	0·054	0·77	0·207	0·161	0·057	0·089	1	2·88	349·31	38·36
Mean	2·11	9·82	26·92	0·0058	0·071	0·87	0·167	0·176	0·064	0·103	...	3·04	340·05	37·75
POJ 2878														
70 in.	3·92	3·35	23·73	0·0194	0·157	1·43	0·213	0·229	0·233	0·127	6	3·36	329·00	42·7
95 in.	3·21	3·36	18·51	0·0143	0·104	1·63	0·209	0·157	0·169	0·168	5	3·37	330·10	32·7
120 in.	2·72	4·63	8·32	0·0124	0·085	0·59	0·071	0·139	0·049	0·059	5	3·62	354·50	39·2
130 in.	2·79	4·55	9·14	0·0107	0·106	1·68	0·056	0·249	0·072	0·113	4	3·28	336·60	26·3
Mean	3·16	3·97	14·93	0·0142	0·113	1·33	0·137	0·194	0·131	0·117	...	3·41	337·55	35·2

NOTE—The market valuation of *gul* is as follows:

	Pundia	POJ 2878
70 in.	Rs. 11	Rs. 10/8
95 in.	Rs. 12	Rs. 10/8
120 in.	Rs. 12	Rs. 10/8
130 in.	Rs. 13	Rs. 11/–

content and low amide and total nitrogen content. Further work on the interaction of different constituents affecting the quality of *gul* is in progress and will be published in a separate paper.

The quantity of *gul* produced per ton of cane is dependent upon its brix and thus the *gul* per acre from POJ 2878 is more than that of Pundia although from the standpoint of tonnages Pundia has come out superior. So also the large fall in tonnages observed in the case of 130 in. is not similarly reflected in the *gul* owing to the improvement in the brix by this treatment. The better-coloured *gul* obtained in this treatment also fetches about two rupees more per *palla* of 240 lb. as compared to that in 70 in. in the case of Pundia. The finer differences in colour in the different treatments as obtained by tintometer readings were not, however, appreciated by the market who did not show any graduated variation in valuation. In the case of POJ 2878, the valuation is practically similar in all the treatments, the variation being two to four annas only per *palla*. Taking all these factors into consideration it would be seen that the treatment of 130 in. becomes unprofitable in the case of POJ 2878 in case the water used for irrigation is charged on volume basis; while in the case of Pundia, this is not evident owing to the higher price obtained in this treatment. As regards other treatments, 95 in. has shown the highest profit in the case of Pundia and 70 in. in the case of POJ 2878. It would be thus evident that lower waterings are likely to be more profitable than higher ones.

(8) *Residual effect*. Surgarcane is grown in three years' rotation of cane, *rabi jowar* and sunn; and the residual effect of the water treatments was determined on both the following crops. The yield data are given in Table VIII as average for the three years succeeding the three sugarcane crops. In the case of *rabi jowar*, the varietal effect is clearly visible, the yield after Pundia being significantly better than that after POJ 2878. There are also indications of the adverse effect of the increased quantities of water. In the case of sunn the results are conflicting, suggesting no effect of either varieties or treatments on its yields. Perhaps the treatment effect has not lasted long as there was only a single crop of cane, but considering the data of *jowar* there seem to be sufficient indications that the deleterious effect of higher waterings such as 130 in. will be accentuated after a series of cane crops in the same land under this manurial treatment. This is also confirmed by the percentage variation in the total nitrogen of the soil after harvest from the initial nitrogen content given in columns 4 and 5 of Table VIII. These figures clearly show a progressive fall in total nitrogen

TABLE VIII

Data to determine the residual effect

—	Yield of *jowar* per acre. Average of three years—1934 to 1937	Yield of sunn per acre. Average of three years—1935 to 1938	Per cent variation in total nitrogen over the preliminary nitrogen content—1934	
			0—12 in.	12—24 in.
1	2	3	4	5
Pundia—	Lb.	Lb.		
70 in.	3057	9430	+21·6	+9·3
95 in.	2562	8992	+6·6	+3·5
120 in.	2900	12092	+7·0	+3·6
130 in.	2520	10045	—6·6	—12·5
Mean	2760	10140	7·05	1·0
POJ 2878—				
70 in.	2675	11300	+8·7	—6·1
95 in.	2650	8680	+16·3	—6·6
120 in.	2557	10745	+2·3	—5·1
130 in.	2500	9000	+3·5	—5·1
Mean	2596	9931	7·7	5·7
C. D. for significance between varieties	140	817	...	...
C. D. for significance between any two treatments	280	1635	...	...

with increased quantities of water in the case of both the varieties. Further, POJ 2878 seems to be more exhausting of nitrogen than Pundia and the yield of *jowar* has definitely supported this as shown above. It would be thus evident that in the case of 150 lb. N as top-dressing, the treatment of 130 in. not only gives low cane tonnages during the season of its application but it further reduces the nitrogen content of the soil which adversely affects the yields of the succeeding crop of *jowar*.

II. TOTAL DELTA: MOVEMENT OF IRRIGATIONAL WATER AND NITRATES IN RELATION TO PLANT GROWTH

Investigations in developmental phases of the cane plant described in section I have given sufficient evidence of the deleterious effect of 130 in. during later stages of the growth phase, which is also well reflected in the final cane tonnages. In the case of other treatments as 70 in., 95 in. and 120 in. not much variation in cane tonnages is observed. Although there had been some adverse effect on growth in 70 in. during the early growth phase, it was obliterated by the later growth and eventually the cane tonnages were practically similar in all the three treatments. Thus if one is to go by these investigations only, one can definitely conclude that from the standpoint of the performance of the various plant phases leading to cane tonnages, the treatment of 70 in. is as good as the other two and therefore higher irrigation than what is given in this treatment should not be necessary under field conditions for the various developmental phases leading to cane tonnages. Studies in the movement of

irrigational water in all these treatments have, however, revealed a different trend and this is described in the following pages.

Methods

Soil moisture was determined by drying a quantity of soil sample in an air oven at 110°C. till a constant weight was obtained. As planting was done by ridge and furrow method at a distance of 4 ft. between furrows, soil samples were collected in the portion of the balk just midway between the level of the irrigational water mark and the bottom of the furrow. In order to fix the spots at start in the plot, a string was laid diagonally and the spots were marked on alternate balks where the string touched the balk. Four such spots were selected in each plot and the soil samples obtained from them were filled in one bottle and taken to the laboratory for moisture determinations. Immediately after taking the sample, this spot was marked with a peg and the next sample was taken just opposite to this. The succeeding periodic samples were taken at one-foot distances from the previous spots in the longer line of the furrows till the ring portion of the plot is reached, when similar procedure is followed again.

Soil samples were collected a day before and three days after every irrigation throughout the life-cycle of the crop. Daily determinations of soil moisture during a few irrigational intervals at start had shown that three days were necessary in this soil for rapid gravitational movements of irrigational water applied and the figure of percentage moisture obtained after three days closely corresponded with the one obtained in the laboratory by the centrifuge method of Briggs and McLean [1910]. Samples for moisture were collected at one-foot depths up to *murum*. The number of samples thus varied from year to year depending upon the depth of the soil which fluctuated from 24 in. to 48 in. The block under experimentation during the first year had a minimum depth while one under the third year's experimentation the maximum one. Two plots were selected for each treatment separately per variety and four spots per plot were sampled at each time to get an average sample, thus getting duplicate readings per variety.

Care was taken to determine whether there could be any contribution from *murum* sub-stratum to the water requirement of the plant by capillary rise. As sampling in *murum* by an augur was not feasible, these studies were carried out in a very shallow soil having a soil depth of about 6 in. and samples were collected of both soil and *murum* by digging a pit up to 3 ft. depth. Certain portion of this area was planted with sugarcane while the other was left fallow. When the plants were about six months old, soil samples were collected at four spots firstly at two days after irrigation in both the cropped and uncropped portions, as the soil was light, and next after 37 days when the plants showed signs of wilting. No irrigation was given during this period. The results are given in Table IX.

TABLE IX

Capillary rise through murum

(Per cent on oven-dry basis, average of four determinations)

—	Depth	Cropped			Uncropped		
		Moisture per cent 2 days after irrigation (30-3-35)	Moisture per cent at wilting—37 days after irrigation	Fall in moisture (Difference of Cols. 3 & 4)	Moisture per cent 2 days after irrigation (30-3-35)	Moisture per cent at wilting—37 days after irrigation	Fall in moisture (Difference of Cols. 6 & 7)
1	2	3	4	5	6	7	8
Soil	0—3 in.	35·3	11·0	24·3	36·8	14·7	22·1
,,	3—6 in.	33·1	15·0	18·1	32·5	19·8	12·7
Murum . .	6—12 in.	19·9	16·1	3·8	20·3	18·4	1·9
,,	12—18 in.	17·6	15·4	2·2	14·8	17·3	+2·5
,,	18—24 in.	16·4	14·8	1·6	14·2	14·2	0·0
,,	24—30 in.	15·6	14·3	1·3	14·4	14·4	0·0
,,	30—36 in.	13·9	14·8	+0·9	11·5	12·4	+0·9

It would be evident from the data of the uncropped portion that there is practically no capillary rise through *murum* throughout this period. The fall obtained from the first depth of *murum* seems to be due more to the downward movement of water than to its upward movement as could be seen from the rise in the moisture content in the immediately next lower depth. In the cropped

portion, on the other hand, there is a definite fall in the moisture content in the *murum* layers. This is found to be due to the actual uptake of moisture by roots which permeate the soft *murum* and in the case of hard *murum* through the cracks in it. In the experimental plots, however, where the soil depth was 2 ft. and more, root studies have shown no such penetration of roots in the *murum* sub-stratum and as there is no capillary rise through *murum*, the field-moisture studies can be taken as a reliable index of the water requirement of the crop for both transpiration and evaporation.

Nitrates were determined by the phenol-disulphonic acid method. For this purpose, soil samples collected before irrigation for moisture determinations were used only at monthly intervals. In addition, samples were collected from the first foot only from the top of the balk at a few periods before earthing up during the latter two years.

Presentation of the data

(*a*) *Soil moisture*. As the trend in the fluctuations in the soil moisture has been practically similar throughout the three years, the data for one year only are illustrated. The moisture content before each irrigation is graphically represented in Fig. 3. Further, the figures of moisture content before and after each irrigation were separately averaged for the different plant phases and are given in Table X. The figures for the germination phase which extends for six weeks have been excluded as the moisture content in this phase has remained practically above 40 per cent approximating the moisture equivalent of the soil type. Besides, during the first three weeks of the germination phase, the irrigational dose was common to all the treatments, after which the differentiation according to the treatments was followed.

TABLE X

Soil-moisture percentage 1935-36

Stage		70 in.			95 in.			120 in.			130 in.		
		0-12 in.	12-24 in.	24-36 in.	0-12 in.	12-24 in.	24-36 in.	0-12 in.	12-24 in.	24-36 in.	0-12 in.	12-24 in.	24-36 in.
1		2	3	4	5	6	7	8	9	10	11	12	13
Formative	1	40·1	38·6	40·2	42·3	41·0	41·3	43·5	42·5	42·7	44·6	43·6	42·5
	2	38·6	36·2	37·6	38·2	36·2	38·4	38·4	37·1	38·1	39·0	40·4	38·8
Grand period (before earthing up)	1	38·4	35·8	36·3	40·8	39·0	39·2	42·5	39·4	40·3	41·6	41·5	40·9
	2	31·1	31·0	31·6	36·1	35·8	35·1	36·2	35·5	35·8	36·9	36·6	36·8
Grand period (after earthing up)	1	39·5	38·2	38·1	40·4	41·2	41·0	43·6	41·9	42·9	41·9	41·9	40·0
	2	35·7	35·8	35·1	37·7	37·9	40·0	38·2	37·5	37·8	37·4	37·4	38·2
Flowering	1	43·3	40·2	39·9	44·4	40·8	40·5	45·6	41·9	42·2	43·4	41·5	40·8
	2	38·9	39·1	38·3	39·7	38·5	40·7	43·1	39·6	40·9	40·3	40·3	41·1
Maturity	1	43·1	41·6	40·1	44·5	44·9	43·8	47·8	44·8	43·6	46·1	43·8	43·0
	2	39·9	41·2	40·8	42·4	41·9	41·1	44·6	43·6	41·4	43·4	43·8	43·3

NOTE—Stage 1—3 days after irrigation
Stage 2—1 day before irrigation

It would be evident from Fig. 3 that in general there is a greater loss of soil moisture during the growth phase leading to the lowering of the moisture content within the irrigational interval of 10 days, and it is only the actual rainfall which has raised it on occasions. Within this period the months of May and June seem to be the months of lowest moisture content or highest water requirement. With the approach of early monsoon conditions the plant starts rapid growth and consequently there is an increased demand for water until changed climatic conditions, e.g. considerable increase in humidity and decrease in maximum temperature are established with the actual break of rains. This early monsoon period is in fact critical in the life of the plant and it is at this time that the moisture content of the soil falls greatly, which in the case of 70 in. has even approached the wilting coefficient of the soil on some occasions. Further, as could be seen from Table X, the irrigational

dose in this treatment is not even sufficient to bring the moisture content to the moisture equivalent of the soil and thus the availability of water remains low throughout the growth phase except when this irrigational dose is supplemented by h'gh rainfall as is apparent from the portion of the curve (Fig. 3) from September onwards. This low moisture content has, in fact, adversely affected the g owth phase (Section I). This is further confirmed by pot culture with different moisture levels maintained throughout the life-cycle of the crop. In this case a level of 40 per cent moisture gave 61 per cent higher yields over a level of 30 per cent moisture which was highly significant, while keeping the moisture content at the moisture equivalent has revealed a deleterious effect, there being actually a fall in yield by 10 per cent. The maintenance of soil moisture at about 40 per cent level would be thus conducive to optimum growth of the crop.

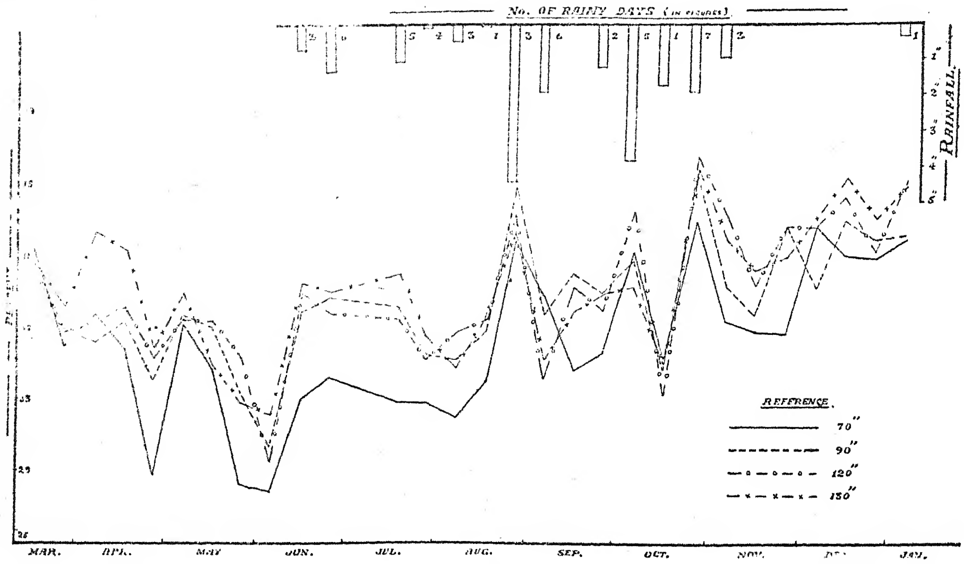


Fig. 3. Periodical moisture studies before irrigation—depth 0-36 in.—1935-36

This insufficiency of irrigational dose in the case of 70 in. is further well illustrated in Fig. 4 in which the dose given per irrigation and the actual quantity of water utilized during a period of 10 days as average of the different phases are represented by pillars. During all the first three phases the irrigational dose has fallen short of the water requirement in this treatment which is more evident during the growth phase. No doubt, as the total delta is inclusive of rainfall, the irrigational dose had to be kept slightly less than what would have been the case if all the total delta could have been given in irrigation. Under field condition the latter alternative would not be possible as some allowance must be made for the ineffective rainfall. It would be further seen that the total water utilized bot' in transpiration and evaporation in this treatment has come to 67 in. as average of three seasons which is practically the same as the treatment. When one considers that there is a possibility of the adverse effect on growth during the early growth phase in this treatment and at the same time there is practically no margin for any ineffective rainfall the risk in recommending this treatment is obvious.

In the case of the other three treatments, the movement of soil moisture before irrigation is practically similar (Fig. 3), the curves showing mostly higher levels of moisture throughout the life-cycle of the plant than in the treatment of 70' in. The moisture content after irrigation (Table X) remains practically the same as it depends upon the moisture equivalent of the soil and as such in the treatments of 120 in. and 130 in. the irrigational dose is generally excessive of the water-holding capacity of the soil. This would be further quite clear from Fig. 4. In the case of 95 in., the irrigational dose practically equals the quantity of water utilized in evo-transpiration throughout the formative and growth phase. It is even slightly less during the flowering stage ; but this shortage can be more than counterbalanced by the proper adjustment of the irrigational dose by reducing it during the maturity stage in which it is rather in excess. In the case of the other two treatments, however, the pillar for irrigational dose is invariably higher than the one for the water utilized in all the phases, clearly bringing out the possible waste of water in these treatments. The figures for the total water

utilized have shown a progressive rise till the treatment of 120 in. followed by a fall in the last treatment of 130 in. which clearly indicates that the latter treatment has exceeded the limit of optimum requirement.

All these data further indicate that the water requirement of the plant is not constant throughout the entire life-cycle of the plant ; but it varies according to the climatic conditions and the stage of crop growth. It may be evident, therefore, that in order to secure the best advantage from the total delta, it is essential to distribute it in either fluctuating intervals or fluctuating doses and not in uniform periodic doses as has been followed in the present series of experiments based on the general system practised in this tract. On the basis of these soil-moisture studies and the figures of daily water requirement calculated from them, a schedule of fluctuating doses is worked out for an experimental trial in the next series and these data will be discussed in a separate paper.

(*b*) *Evo-transpiration ratios*. These ratios have been worked out from the differences in the soil moisture before and after irrigation for millable canes only as no data are available of the total production of dry matter including all the leaves produced. Figures for transpiration ratios alone cannot be also differentiated as under field conditions it is not possible either to exclude evaporation or to calculate it accurately although some idea of it is got by putting pots filled with soil inside the crop and weighing them at fixed intervals. From practical standpoint also evo-transpiration ratios would be of real use as they give a better idea of the total water requirement of the crop. These are, therefore, given in Table XI for all the three years with the actual quantity of water utilized per acre. Estimation of soil moisture separately in the case of Pundia and POJ 2878 has shown very little variation in the figures for the total delta utilized within a period of 12 months although some fluctuations are observed in the periodical samples. Average figures for the total delta are therefore taken for both the varieties and the evo-transpiration ratios are calculated for each variety on the basis of the dry weight of cane.

These figures reveal the dependence of the evo-transpiration ratios on the dry matter produced, the lesser the production of dry matter, the greater these ratios for the same treatment. The wide fluctuations in these ratios from year to year are due to the predominating influence of climate on growth as already discussed in the previous paper. Further work on the inter-relationship of water and manure have shown that these ratios could be reduced even below 400 for the same water treatment (95 in.) by a suitable selection of the manurial

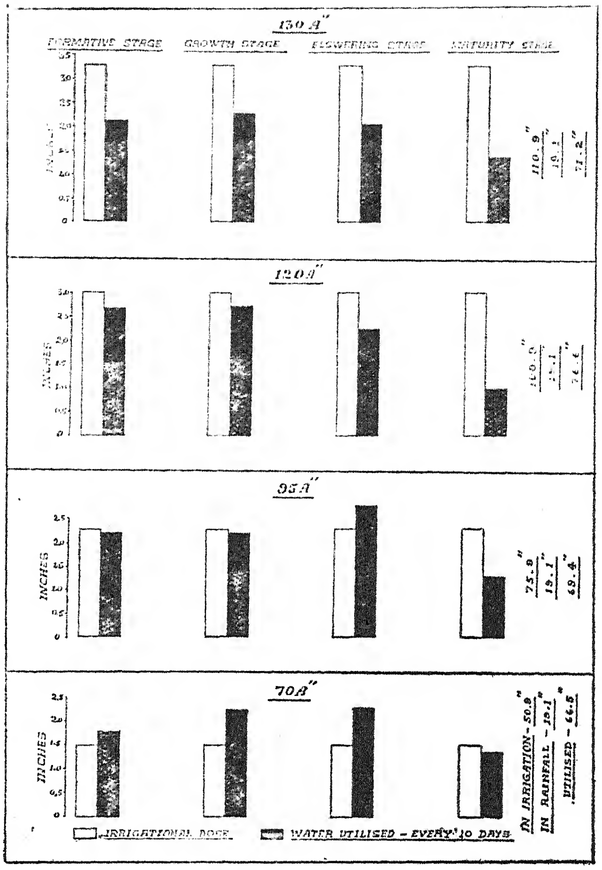


FIG. 4. Periodical water requirement (average of three years—1933-34 to 1935-36)

dose and the varieties. Even in the present case, fluctuations in the ratios for the two varieties are entirely due to differences in the production of dry matter although the total water utilized within a period of 12 months has been practically the same. This is evident from the comparison of the figures of evo-transpiration ratios and the actual water consumed for the years 1933-34 and 1935-36 in the case of 70 in. Although the ratios for these two years varied widely the actual consumption of water during these years was 70·9 and 72·5 acre-inches respectively. It seems, therefore, that from the standpoint of practical irrigation the presentation of the data about actual consumption of water will be of greater utility than of such evo-transpiration ratios which fluctuate largely depending on climate, varieties as well as manuring. It may be remarked here that this figure of the total water requirement is much higher than that obtained by Kulkarni and Inglis [1938]. From their potculture work at Hadapsar in the Deccan Canal

TABLE XI

Evo-transpiration ratios

Treatment	Total delta received in irrigation (in.)	Total rainfall (in.)	Total water received by the crop (in.)	Total water utilized both in transpiration and evaporation per acre	Evo-transpiration ratio		Evo-transpiration ratio—Average of 3 years		Remarks
					POJ2878	Pundia	POJ2878	Pundia	
1933-34									
70 in.	52·06	17·94	70	70·9	702	663	..	..	
95 in.	77·06	17·94	95	68·8	755	615	..	..	
130 in.	112·06	17·94	130	73·4	904	720	..	..	
1934-35									
70 in.	48·99	21·01	70	56·2	828	1003	859	868	
95 in.	72·99	21·01	95	60·9	960	1080	*901	876	* The figures are average of two years
120 in.	98·99	21·01	120	62·9	943	1637	1072	1427	
130 in.	108·99	21·01	130	55·9	914	1037	1001	1027	
1935-36									
70 in.	57·64	18·36	70	72·5	1046	939	..	..	
95 in.	76·64	18·36	95	78·5	1017	933	..	..	
120 in.	101·64	18·36	120	90·4	1072	1186	..	..	
130 in.	111·64	18·36	130	84·4	1184	1325	..	..	

NOTE.—During 1933-34 moisture studies were not carried out in the treatment of 120 in.

tract, they have concluded that about 4/5th of an acre-inch of water is all that is required to produce a ton of green cane, or in other words a 40-ton crop requires only 32 in. of water exclusive of evaporation or 47 in. inclusive of the same. It is rather a moot point whether this low figure is entirely due to the location of the experimental work at a place where the humidity is higher than what is obtained here. Their field experiments on irrigational quantities, which were also conducted practically simultaneously, have not, however, supported this low figure. In this case, the treatment of 75 acre-inches has come out the best and as it seems that they have not made any allowance for the rainfall in these water treatments, this figure practically agrees with the treatment of 95 in. of ours. This dissimilarity of results among pot culture and field experiments obtained by these authors has, in fact, justified our viewpoint that for securing conclusive data of practical value, field experimentation of the type described by us will be more suitable.

Nitrates. The nitrate N was determined in the soil samples preserved at monthly intervals from those taken for moisture estimations. These data were calculated as percentage deviation from the original nitrate content of the soil and are illustrated graphically in Fig. 5 for one year only as it almost represents the trend of fluctuations in the different treatments for other years also. In addition, samples were collected from ridge only at a few periods till earthing up during the latter two years. In this case the data are given in Table XII, also for the same year. The results clearly illustrate the fall in nitrates with increased water quantities suggesting leaching of nitrates. This is very well brought out in the data given in Table XII. The comparison of figures with those in the furrow shows that the ridge forms a repository of nitrates which are either accumulated by the capillary rise or by being formed *in situ* due to the intensification of the process of nitrification caused by better aeration. The root-system is found, however, to permeate throughout the mass, and as the growth in the higher water treatments is found to be slightly better at this time with the possibility of greater absorption of nitrates by the plant, the observed fall in nitrates with increasing

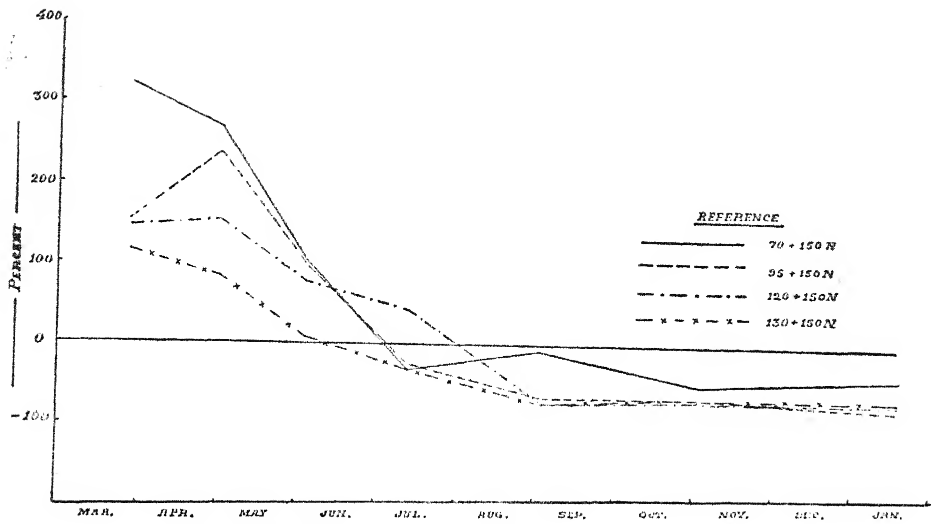


FIG. 5. Periodical deviation of nitric N from preliminary sample—1934-35

quantities of water cannot be entirely attributed to their leaching down to lower layers ; such wide variations, however, do indicate that there must be appreciable loss of nitrates by leaching with increased quantities of irrigation as in the case of 120 in. and 130 in.

TABLE XII

Percentage increase of nitrate nitrogen in ridge over the nitrate content at start 1934-35

Treatment	12 March	18 May	27 June	Actual nitrate N content on 27 June 1934 mg. in 100 gm. of air dry soil
70 in. . . .	609	1079	317	0·51
95 in. . . .	248	414	73	0·22
120 in. . . .	243	93	—10	0·09
130 in. . . .	138	75	—50	0·05

Some laboratory studies were also carried out to see whether such high irrigational treatments do affect the nitrifying power of the soil. For this purpose, soil samples were collected from different treatments at the time of earthing up and were mixed with safflower cake which was to be applied at the time of earthing. These were then immediately filled in earthen-ware pots after making up the moisture content to the moisture equivalent in all the cases. At intervals, a definite portion of the soil was removed and ammonia and nitrates were determined. For ammonia, the soil was distilled with MgO. Every fortnight the moisture content of the soil was made up to the moisture equivalent and care was taken to see that it never fell below 35 per cent during the course of experimentation. Periodical data for both ammoniacal and nitrate N as percentage of the total N are given in Table XIII. The results indicate consistent diminishing microbiological activity leading to less mineralization of cake nitrogen in the soil in the case of 130 in. This low microbiological activity suggests that such heavy irrigation is not conducive to the maintenance of proper tilth required for the purpose and as a result, a larger portion of

TABLE XIII

Ammonification and nitrification of safflower cake percentage of total N

Treatment	15 days		1 month		2 months		3½ months		4½ months		Total mineralization
	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	
Cake + 70 in. .	14·4	0·20	20·9	2·2	17·3	6·8	11·5	9·2	8·3	7·1	19·6
Cake + 95 in. .	12·5	0·20	19·1	2·6	14·5	7·3	9·7	8·6	6·6	6·1	17·4
Cake + 120 in. .	13·6	0·03	20·4	2·6	13·6	6·4	8·8	8·4	6·5	5·7	17·2
Cake + 130 in. .	11·7	0·03	15·6	1·9	11·7	5·4	7·8	7·0	6·3	5·5	14·4

cake, which is the only top-dressing applied at earthing up time, will remain unavailable. The fall in growth at later stages in this treatment seems to be thus partly due to the non-availability of the cake owing to its less nitrification. In the case of the other treatments, 70 in. have shown slightly better mineralization than the other two.

General discussion and conclusions

The problem of the exact water requirement of sugarcane under field conditions is of extreme importance in the Deccan Canal tract, where sugarcane is entirely grown on irrigation from the canals which are constructed at a great cost. A comprehensive programme of research has been, therefore, planned out in a series of experiments, and the first series described in these two parts comprises investigations on the minimum and also the optimum delta for the same manurial dose. These investigations have been mainly carried out by field experiments after taking proper precautions to maintain accuracy in water quantities by carrying the measured volume of water directly to the field by means of hume pipes without any loss in transit. A continuous record was also kept of the fluctuations in moisture in the field by laboratory studies. These data are given in section II while the developmental behaviour of the plant under varying treatments is described in section I.

Among the four water treatments of 70, 95, 120 and 130 acre-inches, sufficient evidence is available as regards the deleterious effect of 130 in. This harmful effect is found to start only at later stages of the growth phase and is traced to deficiency of mineral nutrients specially nitrates. It has been found that this deficiency is caused by both the leaching down of nitrates and the adverse effect of such heavy irrigation on the microbial activity of the soil, the latter reducing the availability of nitrogen in cake applied as top-dressing at earthing up time. That there is a fall in growth in this treatment is further reflected in cane tonnages, the reduction being quite significant in certain seasons and also in the average of the three seasons when compared to the other treatments. Studies in the residual effect have also revealed a fall in total nitrogen and in the yield of the succeeding crop of *jowar* in this treatment. There is thus sufficient evidence to indicate a close relationship of water and nitrogenous top-dressings. The only point in favour of this treatment has been the early maturity leading to higher brix and purity, and better-coloured *gul*. In the case of Pundia, this *gul* has fetched about two rupees more per *palla* and from the commercial standpoint has made up for the fall in yield as compared to the treatment of 70 in. In the case of POJ 2878, the difference in the colour of *gul* from different treatments was not of sufficient magnitude to attract the attention of the market and the prices have been practically similar in all cases. From the standpoint of commercial cane sugar, it has not also come superior to the other treatments.

Coming to the actual use of water in evo-transpiration this treatment seems to have exceeded the limit of optimum requirement as, while there has been a progressive rise in evo-transpiration with increased deltas up to 120 in., this treatment which is immediately higher to it has shown a tendency towards reduction in this figure. It is not, however, quite clear at this stage as to whether this can be entirely ascribed to the depressed plant activity or to the possibility of the maintenance of higher humidity in this treatment which, as is well known, reduces the transpiration.

Among the remaining three treatments, the treatment of 70 in. has shown some adverse effect on growth during the early growth phase, while the other two treatments have shown similar developmental performance throughout. This decreased rate of growth in the case of 70 in. is found to be due to the deficiency of soil moisture during this period caused by the insufficiency of the irrigational dose and it is only the rainfall of September which raised the moisture content of the soil sufficiently to accelerate the rate of growth. It is, however, observed that this low irrigational dose reduces the loss of nutrients by leaching down to lower layers by constant irrigation and therefore the growth continued in this treatment when it had practically ceased in the case of others. Consequently this treatment eventually made up in growth and also in cane tonnages, thus equalling those of the other two at the time of harvest. There is, however, an indication of the progressive rise in brix and purity with increased water quantities.

It would be thus evident that in case we had not such detailed observations on the developmental performance and the data on soil moisture, we would have without hesitation recommended 70 acre-inches to be the minimum water requirement under field conditions by following the general procedure in vogue of taking cane tonnages as the criterion for finally judging the efficiency of the treatments. It must be, however, remembered that all these water treatments are inclusive of rainfall and under field conditions where rainfall cannot be excluded, some allowance must be made for its precarious nature by reserving a portion of the total delta while fixing the irrigational dose in each treatment. Thus the dose at each irrigation would be slightly less than what would have been the case if the total delta was given in irrigation alone in uniform doses. In the case of 70 in., this irrigational dose has been insufficient on many occasions to make up for the loss of moisture, which has adversely affected the growth

and it is only when it is supplemented by rainfall that this adverse effect has disappeared. It is further observed that the actual loss in evo-transpiration comes to about 67 in. in this treatment, i.e. practically equal to the fixed total delta and there would be thus no margin for the ineffective nature of the rainfall when it comes in torrents—a very common feature in this tract. It would be thus risky to recommend this total delta for adoption in the general agricultural practice in this tract as its success would entirely depend upon the favourable season of well-distributed rainfall.

In the case of 95 in., on the other hand, the periodical irrigational dose almost balances the loss of water during the interval and is thus independent of rainfall. This treatment thus contains sufficient allowance for the ineffective rainfall without any excess at the same time in the irrigational dose. Such is not the case with 120 in. in which the irrigational dose is far in excess of the water requirement throughout all the different phases of plant life. At the same time, both the developmental behaviour and cane tonnages have shown no additional advantage of this higher delta over 95 in. and all this excess quantity is therefore a mere waste. Taking all these factors into consideration, 95 in. is considered to be the minimum water requirement under field conditions and 120 in. to be the optimum one for a manurial dose of 150 lb. N.

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VARIATIONS IN THE MEASURABLE CHARACTERS OF COTTON FIBRES

V. VARIATIONS CAUSED BY CHANGE OF PLACE AND SEASON

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(With Plate XIX and four text-figures)

MANY workers have studied the influence of environment on the yield of cotton but only a few have correlated its effect on the quality. Balls [1915] investigated the water requirements of cotton and showed that a deficiency in the water supply would affect the development of lint. Hawkins and Serviss [1930] studied the development of the cotton fibre and incidentally correlated the variations in temperature with lint development. They have not, however, made proper allowances for those due to changes in the plant age. Peirce and Lord [1934] worked on the same cotton grown in two places and found considerable variation in the degree of maturity. Patel and Srinagabhushana [1936] examined the effect of growing the same cottons in three places in Gujarat. They observed appreciable differences in fibre weight per centimeter and maturity. It is proposed to record here the variations observed when the same set of cottons were grown at two different places, Coimbatore and Srivilliputhur, for five seasons. It may be mentioned that at Coimbatore the seeds are sown in September and the pickings are done in February and March. At Srivilliputhur, on the other hand, the plants are grown during the hot weather from March to August and the pickings are done in July and August.

MATERIAL AND METHODS

The material was collected from pure strains of Cambodia cotton (*G. hirsutum*) evolved at the Cotton Breeding Station, Coimbatore. In the first year there were 14 strains, in the second 11, in the third 28, in the fourth 9 and in the fifth year 8. The following characters were determined :

1. Seed weight,
2. Lint weight,
3. Ginning percentage,
4. Mean fibre length,
5. Mean fibre weight per centimeter,
6. Unit fibre weight,
7. Standard fibre weight,
8. Number of fibres per seed, and
9. Maturity percentage.

In addition the mode of development of fibres was also studied. The first three characters were determined by taking four lots of 100 seeds each according to the method described by Hilson [1922]. Mean fibre length was obtained by two Balls sorter tests on separate slivers according to the method followed at the Technological Laboratory, Bombay, [Ahmad, 1933]. The unit fibre weight and fibre weight per centimeter were obtained by weighing whole fibres [Ahmad, 1933]. The standard fibre weight was calculated according to the new formula of Peirce [1938]. The number of fibres per seed was obtained by dividing the lint weight per seed by the unit fibre weight [Iyengar, 1934]. The maturity was determined by the use of Gulati and Ahmad's [1936] maturity slide.

For the study of the length and thickness development, flowers of Co 2 were labelled on the day of opening and bolls of various ages were collected and immediately killed in form-acetic-alcohol. Ovules from the middle position of 9-seeded locks were used in the present study. Ovules of 0 to 6 days' age were embedded in paraffin for cutting sections. The sections were cut to 10 μ thickness and stained with haematoxylin. The number of fibres sprouting on the seed surface was counted on the five middle sections and their average was taken. The length and breadth of the middle section were also determined with the help of which the approximate total number of fibres per seed was calculated as shown in the Appendix. Four to six ovules have so far been studied for each of the ages one, two and four days, for each of the two places. Those of 4 to 29 days age from bolls collected at Coimbatore and of 4 to 19 days age in the case of collections made at Srivilliputhur were used for measuring the fibre length. In the latter samples the locks of cotton were immersed, as suggested by Berkley [1939], in boiling water for a few minutes to disentangle the fibres for the length measurement. The fibres sprouting on the right side of the seed, when the funicle is pointing away from the observer, were used for measuring the length. Keeping the seed under water the fibres were gently separated and straightened by means of a needle. The approximate length of the tuft from the centre of the seed was then measured by means of a pair of dividers. Ten measurements were made for each age. For the measurement of wall thickness the fibres of the same region were utilized. A tuft of about 150

fibres was separated by means of a needle and pulled out from the seed. This tuft was gently spread out on the Gulati and Ahmad slide and mounted in a mixture made of equal proportions of water, glycerine and alcohol. Fibre wall-thickness was determined at one place (about the middle) for each fibre by moving the slide on the stage of the microscope. Six tufts taken from different seeds were examined for each age. The diameter of the uncollapsed fibre was determined by mounting and measuring the fibres as in the case of wall-thickness measurement. Six samples from different bolls of the highest available age were studied for each place. The surface area of the seed was determined by the method described by Iyengar [1929 and 1941]. One hundred seeds, in four lots of 25 each, were examined for each of the eight strains studied in the final year. The volume of the seed was also determined by the displacement of kerosene oil.

For statistical analysis Student's method was employed for testing the differences within the same year, and anlaysis of variance was used when differences for all the years were combined together. In the anal sis of variance only six strains which were common to the last four years were utilized, the results for which are found in Table VIII.

Results

The individual results of each character for the five different years are not recorded for the sake of brevity. The mean differences between the two places with their statistical significances are, however, given in Table I. The values for the variance ratio (e^{2z}) along with its significance are given in columns 17 and 18 of Table I. The analysis of variance is found in Table VII.

It will be seen that most of the differences are highly significant and many of the characters behave uniformly in almost all the years. (1) Lint weight, (2) ginning percentage, (3) number of fibres per seed, and (4) mean fibre length exhibit the same kind of behaviour in all the five years, the first three characters being greater and the last one smaller at Coimbatore (Fig. 1).* Two other characters also, viz. standard fibre weight and the proportion of mature fibres, behave alike in four out of the five years, the former being higher and the latter lower at Coimbatore. In three of the five years fibre weight per cm. is significantly greater at Coimbatore. In the other two years the differences are either way and both of them are not significant. Unit fibre weight and immature fibres behave differently in different years. In only one year the seed weight records a significant increase at Srivilliputhur.

*In Fig. 1 the differences expressed as percentage of the mean are given for all the properties except mature and immature fibres percentages, for which the actual differences are recorded

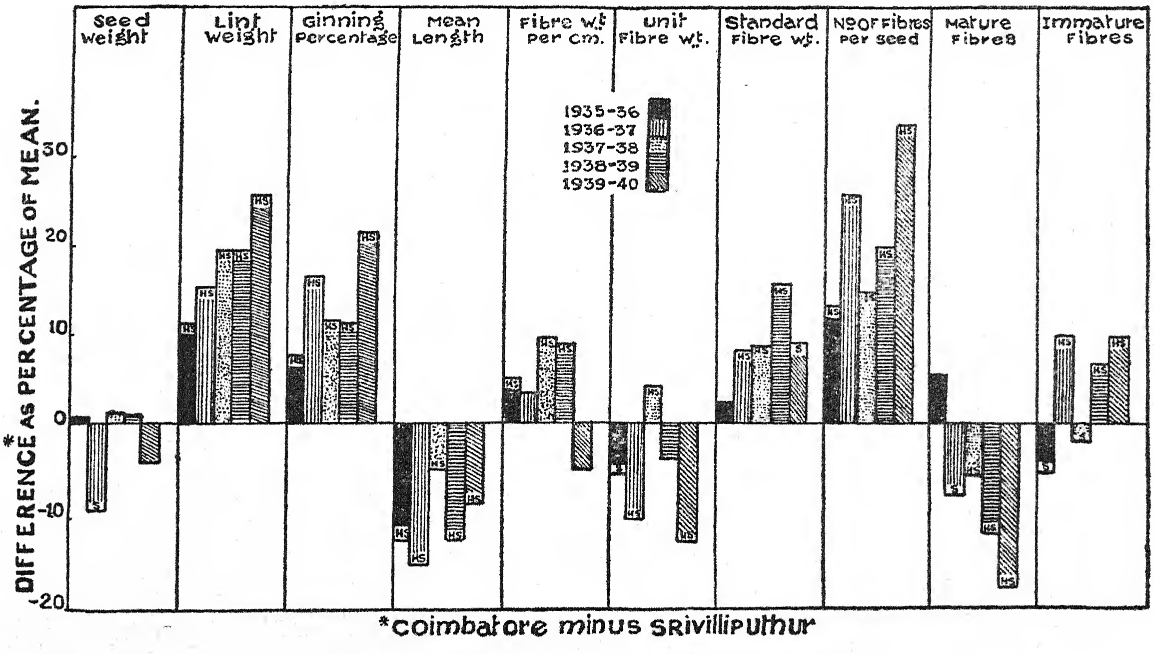


Fig. 1. Variation of characters with change of place

TABLE I

Difference between Coimbatore and Srivilliputhur

Property	1935-36			1936-37			1937-38			1938-39			1939-40			By analysis of variance		1939-40 September to March at both places		
	Difference*	t	Significance	Difference	t	Significance	Difference	t	Significance	Difference	t	Significance	Difference	t	Significance	e^{2z}	Significance	Difference	t	Significance
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Number of pairs of samples		14			11			28			9			8		7			5	
Seed weight in m. gm.	0·42	0·31	N	—10·5	2·78	S	1·71	0·73	N	1·67	0·56	N	—4·38	1·70	N	22·7	HS (—)	8·0	5·1	HS
Lint weight in m. gm.	6·54	7·30	HS	9·42	7·85	HS	12·3	15·20	HS	12·11	8·97	HS	15·88	35·54	HS	160·7	HS (+)	11·2	5·9	HS
Ginning percentage	2·55	7·75	HS	5·78	9·25	HS	4·21	10·80	HS	4·33	18·9	HS	7·25	21·18	HS	322·8	HS (+)	3·0	5·3	HS
Fibre length in inch	—0·114	8·50	HS	—0·140	16·05	HS	—0·051	3·70	HS	—0·116	6·28	HS	—0·086	7·67	HS	134·5	HS (—)	0·01	0·98	N
Fibre weight per cm. in 10^{-6} gm.	0·086	3·15	HS	0·046	1·29	N	0·130	9·82	HS	0·123	3·42	HS	—0·012	1·37	N	6·6	S (+)	0·08	1·6	N
Unit fibre weight in 10^{-6} gm.	—0·194	2·20	S	—0·360	3·61	HS	0·135	3·28	HS	—0·114	1·07	N	—0·496	3·60	HS	6·5	S (—)	0·22	1·3	N
Standard fibre weight per cm. in 10^{-6} gm.	0·004	0·05	N	0·196	25·10	HS	0·159	8·03	HS	0·252	11·6	HS	0·140	3·25	S	74·0	HS (+)	0·06	1·1	N
Number of fibres per seed in 1000's	2·18	5·05	HS	4·68	6·33	HS	2·58	6·54	HS	3·71	8·17	HS	6·56	9·85	HS	68·5	HS (+)	2·3	2·8	S
Mature fibres per cent	5·29	2·07	N	—7·9	2·83	S	—5·0	4·39	HS	—12·1	4·79	HS	—18·25	7·75	HS	32·2	HS (—)	5·0	2·1	N
Immature fibres per cent	—5·26	2·87	S	9·55	6·70	HS	—1·96	2·34	S	6·3	3·77	HS	10·25	6·26	HS	21·7	HS (+)	1·8	1·0	N

HS = Significant for $P = 0·01$
S = Significant for $P = 0·05$
N = Not significant
*Coimbatore values—Srivilliputhur values

The results of the analysis of variance are substantially in agreement with the findings made above. Lint weight, ginning percentage, fibre weight per cm., standard fibre weight, number of fibres per seed and immature fibres are significantly ($P=0\cdot01$) greater at Coimbatore, while mean length and the proportion of mature fibres are significantly ($P=0\cdot01$) less; unit fibre weight and seed weight are likewise significantly ($P=0\cdot05$) less at this place.

From the foregoing it may be concluded that at Srivilliputhur (1) the mean fibre length is greater, (2) the fibre weight per cm. as well as the standard fibre weight, or in other words, the diameter of the fibre cells, is smaller, (3) the maturity of the fibre is greater, and (4) the number of fibres sprouting on the seed is less. They indicate that the quality of cotton is considerably improved when grown at Srivilliputhur, though it is accompanied by a reduction in the number of sprouting fibres on the seed.

The rate of development of the fibres in the two places may now be considered. The period of growth of the cotton plant is about a month shorter at Srivilliputhur than at Coimbatore. On *a priori* grounds a reduction in the maturation period of the boll can be anticipated. That means the lengthening phase of the fibre will proportionately get shortened. This will mean that the fibre will be shorter at Srivilliputhur. But actual observations show it to be exactly opposite. It would follow that the rate of lengthening must be greater at Srivilliputhur. A similar reasoning in the case of wall-thickness points to an increased rate of thickening of the fibre of this place. The results obtained show that at Coimbatore the average maturation period (mean of 358 bolls) is $53\cdot7\pm0\cdot23$ days while at Srivilliputhur it (mean of 704 bolls) is only $40\cdot0\pm0\cdot14$ days, i.e. about 14 days shorter. The details of the lint length development are given in Table II and Fig. 2. It will be seen that at Coimbatore the lengthening phase continues up to about 23 days while at Srivilliputhur it ends by the 16th day. The rate of lengthening is considerably higher at the latter place (Fig. 2), the highest value is about 4·55 mm. per day on about the 15th day. The highest rate at Coimbatore is only 3·05 mm. per day. Logistic curves [Mills, 1938] fitted to the data of the length development show that at Coimbatore the length of the fibre, l, is given by $\frac{10,000}{l}=281\cdot61+9206\cdot20\times0\cdot6280^d$ and at Srivilliputhur by $\frac{10,000}{l}=247\cdot79+4597\cdot66\times0\cdot5597^d$, d being the time unit of two days, starting from the fourth day. The development of the secondary wall is recorded in Table III. Bolls of age beyond 53 days

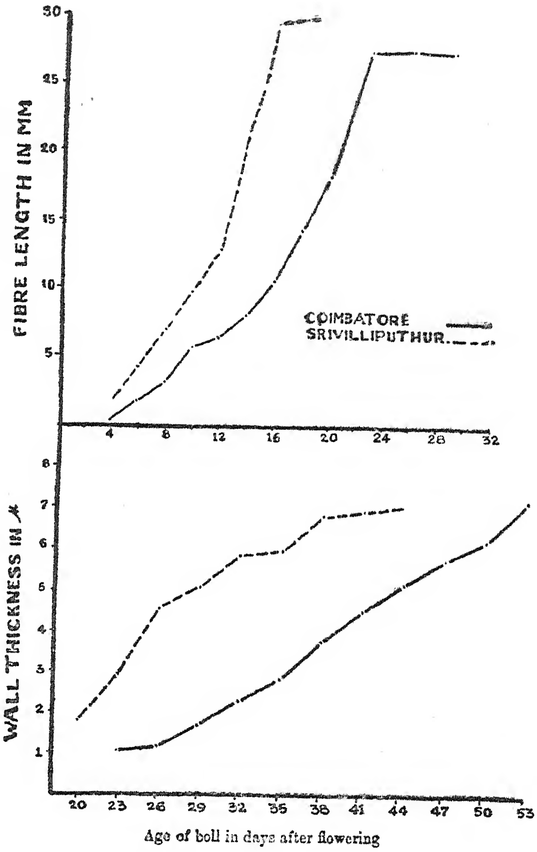


FIG. 2. Length and thickness development of fibres

were not available at Coimbatore while at Srivilliputhur those of 44 days were the oldest obtained. The results show that the maximum wall-thickness of about 7μ is deposited in about (53—23) 30 days at Coimbatore. The same amount of thickening is produced at Srivilliputhur in about (40—16) 24 days only. The rate of secondary deposition is highest in the earlier stage at the latter place, it being as high as 0·36μ to 0·48μ per day. At Coimbatore, on the other hand, the highest rate is at about the middle of the thickening period; the maximum value 0·28μ per day is much less than that a Srivilliputhur. Logistic curves fitted to the data of the secondary thickening show that at Coimbatore the thickness of the wall, t, is given by $\frac{10,000}{t}=1212\cdot46+9428\cdot08\times0\cdot6931^d$ and at Srivilliputhur it is given by $\frac{10,000}{t}=1360\cdot96+3926\cdot82\times0\cdot5559^d$, d being the time interval of three days starting from 23 days at Coimbatore and 20 days at Srivilliputhur.

The mean diameter of the uncollapsed fibre is found to be $22\cdot38\mu\pm0\cdot286\mu$ at Coimbatore and

TABLE II

Length development of fibres in mm. (Mean of 10 determinations in each case)

Age of ovules after flowering	COIMBATORE 1939-40				SRIVILLIPUTHUR 1940			
	Length		Rate of lengthening per day		Length		Rate of lengthening per day	
	Mean ±	S.E.	Mean ±	S.E.	Mean ±	S.E.	Mean ±	S.E.
Days								
4	0·84	0·032	0·52	0·029	1·79	0·066	1·24	0·056
6	1·88	0·051	0·68	0·047	4·27	0·092	1·37	0·076
8	3·25	0·079	1·28	0·082	7·01	0·121	1·42	0·106
10	5·80	0·145	0·35	0·094	9·85	0·174	1·50	0·128
12	6·50	0·122	0·88	0·156	12·85	0·188	4·45	0·204
14	8·25	0·285	..	..	21·75	0·361	3·20	0·482
15	..	..	1·22	0·185	24·95	0·320	4·55	0·452
16	10·70	0·236	..	..	29·50	0·320	0·20	0·410
17	..	..	2·38	0·196	29·70	0·256	0·15	0·317
18	14·45	0·312	..	..	29·85	0·187	0·15	0·300
19	..	..	1·98	0·228	29·90	0·234	..	..
20	18·40	0·322	3·05	0·172	..	..	..	..
23*	27·55	0·408	0·00	0·207	..	..	..	..
26	27·55	0·466	—0·08	0·203	..	..	..	..
29	27·30	0·394	..	..	..	..	..	..
Mean	..		1·20		..		1·85	

*As it was thought that the lengthening phase might not extend beyond 20 days after flowering, bolls of age differing by single day only after 20 days were not killed at Coimbatore. At Srivilliputhur this defect did not arise as the lengthening phase ended by 16 days

TABLE III

Degree of thickening in μ for different ages (Mean of six determinations in each case)

Age of ovule after flowering	Coimbatore 1939-40				Srivilliputhur 1940			
	Wall thickness		Rate of thickening per day*		Wall thickness		Rate of thickening per day*	
	Mean ±	S.E.	Mean ±	S.E.	Mean ±	S.E.	Mean ±	S.E.
Days								
20	..	..	..	..	1·72	0·049	..	..
23	1·05	0·006	..	..	2·93	0·133	0·48	0·011
26	1·16	0·006	0·10	0·002	4·59	0·042	0·36	0·033
29	1·68	0·011	0·19	0·001	5·09	0·150	0·21	0·046
32	2·28	0·002	0·19	0·011	5·85	0·276	0·15	0·034
35	2·81	0·064	0·26	0·010	6·00	0·144	0·17	0·058
38	3·82	0·061	0·28	0·042	6·85	0·211	0·16	0·025
41	4·51	0·241	0·24	0·029	6·98	0·052	0·04	0·040
44	5·24	0·163	0·22	0·052	7·11	0·113	..	..
47	5·80	0·204	0·17	0·063	..	..	..	..
50	6·26	0·340	0·23	0·043	..	..	..	..
53	7·18	0·157	..	..	..	..	..	..
Mean	..	..	0·240	..	..	..	0·279	..

*Mean increase for six days' interval

$21{\cdot}47\mu \pm 0{\cdot}182\mu$ at Srivilliputhur. The difference is statistically significant for the 5 per cent point, indicating that the fibre is finer at Srivilliputhur, which conforms with the finding made previously from the results for the standard fibre weight.

The results obtained for the number of fibres per section and per seed for the different ages are given in Table IV.

TABLE IV

Number of fibres sprouting on the ovule

Age of ovule	Per section		On the whole ovule		Diameter of fibre cell in μ	
	Coimbatore	Srivilliputhur	Coimbatore	Srivilliputhur	Coimbatore	Srivilluputhur
1 day	93	141	6,800	10,400	11·7	14·4
2 days	179	160	12,600	9,000	14·4	14·9
4 days	226	181	10,700	9,500	17·2	16·8
Fully mature seed			19,000	13,000		

It should be stated at the outset that further work is necessary before definite conclusions can be drawn. The following observations may, however, be made tentatively. The mean number of fibres per section is seen to increase with age at Coimbatore but at Srivilliputhur the increase, if any, is negligible. The calculation of the total number of fibres on the whole seed is subject to error. Bearing this in mind it may be stated that the number of fibres per seed is less at Coimbatore on the first day; at Srivilliputhur, however, the differences cannot be said to be significant. Balls [1915] stated that the number of fibres sprouting on the seed was determined by the environmental conditions on the day of flower opening, there being no further differentiation

afterwards. Gulati [1930] and Ayyar and Ayyangar [1932] and others showed that further sprouting of fibres also does take place. When the present results are considered in the light of the above findings it looks as if the remark of Balls is correct at Srivilliputhur and that of the others at Coimbatore. It may be mentioned here that the cotton which Balls [1915] studied was also grown in summer as at Srivilliputhur. Further confirmation is, however, essential to substantiate this conclusion.

Between the two places the difference in the number of fibres is very conspicuous in the one day-old ovule. The development of the fibre is also considerably different as can be seen in Plate XIX. The Coimbatore ovule has on it very small protrusions, hardly visible, while the Srivilliputhur one shows out the fibres very clearly. The number is also much more at the latter place. In ovules of age of two days the number of fibres per section appear to be the same in both the places; but in four days old ones the Coimbatore value rises very much higher than the other. Thus starting with much smaller number at Coimbatore it overtakes and leaves behind the Srivilliputhur value by the fourth day.

The diameter of the fibre cell, at the point of sprouting, appears to increase with age at Coimbatore, while at Srivilliputhur the value for the fourth day alone is greater than the other two. Further determinations are to be made on this point.

To account for the reduced number of fibres per seed at Srivilliputhur, Dr Nazir Ahmad suggested that the surface area of the seed be determined at both the places to see if it is less at Srivilliputhur. The results obtained are given in Table V.

TABLE V

Differences in seed characters (Coimbatore minus Srivilliputhur)

	Area × K	Seed weight in mgm.	Seed volume in c.c.	Density of seed in gm./c.c.	No. of fibres per seed in 1000's	No. of fibres per unit area × K[1]
Value	—0·485**	—0·0055	—0·0098*	n* 0·0274	6·56** 34 per cent of Co value	3·72** 46 per cent of Co value
S.E.	0·0697	0·00341	0·00362	0·0131	0·666	0·364

** Significant for $P=0\cdot01$ n*Near significance for $P=0\cdot05$ * Significant for $P=0\cdot05$

It will be seen that the surface area, instead of being less, is significantly more at Srivilliputhur. As a consequence the number of fibres per unit area of the seed surface gets reduced still further at this place. The difference in this character is as high as 46 per cent of the Coimbatore value, while the corresponding difference in the total number of fibres on the whole seed is only 34 per cent.

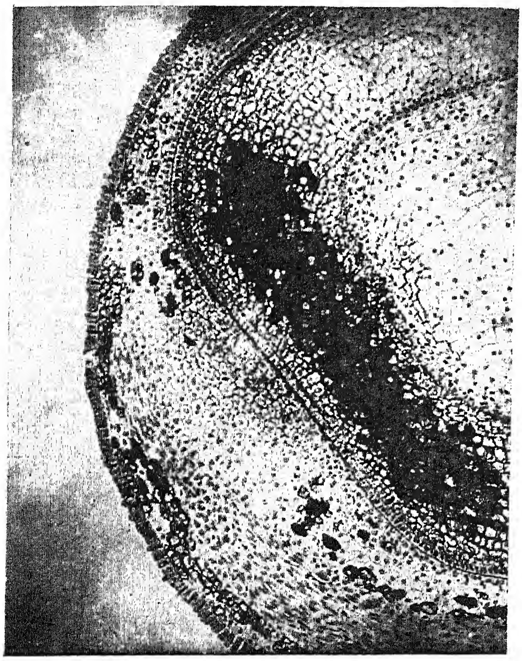
The difference in the surface area is seen above to be significantly greater at Srivilliputhur. But it was found that the seed weight was not significantly different. These two findings are apparently contradictory. But the results obtained for the seed volume offer an explanation, the volume being significantly greater at Srivilliputhur. The higher volume reduces the density of the seeds here, the difference in which though not statistically significant is near the critical value.

DISCUSSION OF RESULTS

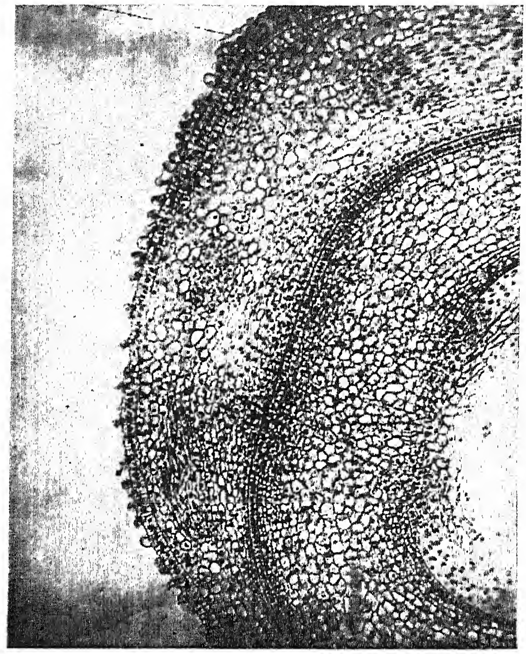
The changes in the climatic and fertility factor in the two places can now be examined with a view to correlate the observed variations in fibre characters with any of them. It will be seen from Fig. 3 that the temperatures during the earlier phases of the plants' growth at Srivilliputhur are considerably higher than those of the corresponding stages at Coimbatore. The mean§ weekly temperature at the latter place ranges from 73°F. to 80° F., except in the last four weeks (Fig. 3), whereas at Srivilliputhur the mean temperature is never below 82°F. with a maximum reaching to 88°F. During the grand period of the plants' development and during flowering and boll-formation the mean temperature at Coimbatore is very low (73°F. to 77°F.) while at Srivilliputhur it is much higher (85°F. to 88°F.) The higher temperature is associated with greater solar radiation. Even in the general shape of the temperature curve there is a considerable difference. While at Coimbatore the temperature falls and

§The mean weekly temperature was obtained by determining on the thermohygrograph chart the area enclosed by the temperature curve, the two 10 o'clock lines at the beginning and the end of the week and the zero degree line and calculating the mean temperature therefrom. The mean weekly relative humidity was similarly determined from the relative humidity curve, the 8 o'clock lines being used in this case.

Section of a one day old ovule of the strain of Cotton Co2 (*G. hirsutum*)

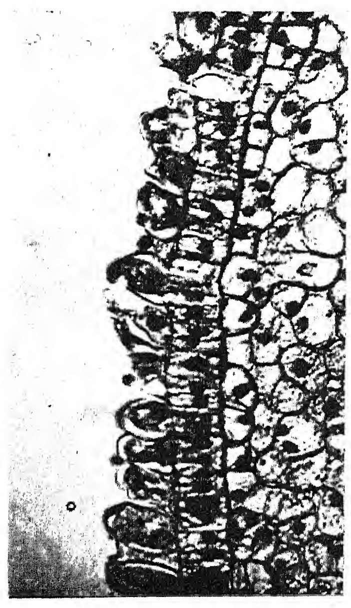


Grown at Coimbatore (×100)



Grown at Srivilliputhur (×100)

Grown at Coimbatare (×400)



Grown at Srivilliputhur (×400)

then rises (Fig. 3) during the life of the plant, at Srivilliputhur it appears to rise and then fall.

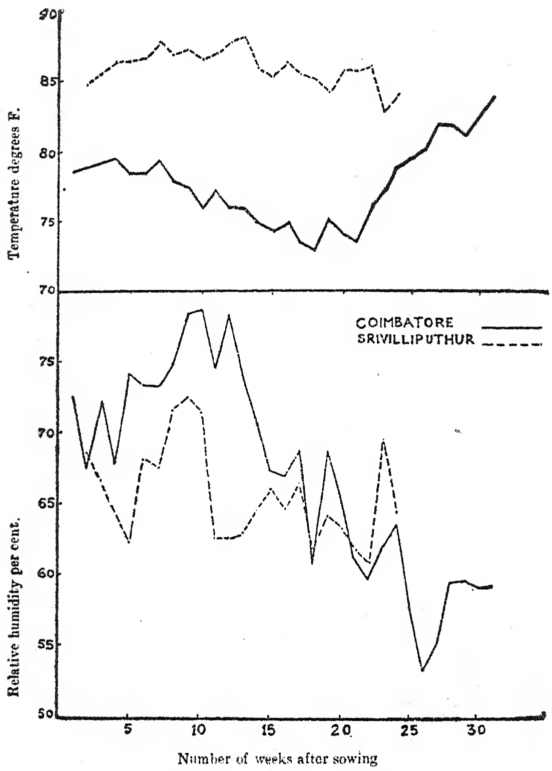


FIG. 3. Variation of temperature and relative humidity (Mean value for three years)

Coming next to the mean weekly relative humidity it will be seen that there are distinct differences (Fig. 3) between the two places, though not as conspicuous as in temperature. At Coimbatore, after a preliminary rise there appears to be a gradual fall with the advance of age, while at Srivilliputhur the general trend is not distinct. Between the 10th and the 16th weeks after sowing, that is, when most of the floral buds are being formed, the mean weekly relative himidity is considerably higher at Coimbatore (Fig. 3).

With regard to the rainfall it may be stated that the two places receive nearly similar amounts ; the distribution of rainfall is also fairly similar. The quantity of water given in the irrigations is slightly more at Srivilliputhur.

For the comparison of the relative fertility of the soils of the two centres the soils were analyzed by the Government Agricultural Chemist and their results are given in Table VI. The Government Agricultural Chemist remarks on them: 'In general the soil from the Srivilliputhur taluk contains mechanically more finer fractions than the Coimbatore soils. The available phosphoric acid and pH of the surface soil from Srivilliputhur taluk are more favourable and also the water-soluble salts are less as will be evident from the values obtained from their electrical conductivity'. The soil at Srivilliputhur may, therefore, be taken to be relatively more fertile than the soil at Coimbatore.

Summing up the differences it may be stated that at Srivilliputhur (1) the temperature and solar radiation are considerably higher, (2) the

TABLE VI

Results of analysis of 12 samples of soil from Cotton Breeding Station, Coimbatore and Srivilliputhur

Property in	Field No. 7, C. B. S., Coimbatore				Field No. 8, C. B. S., Coimbatore				Srivilliputhur			
Depth in.	0-6	6-12	12-24	24-36	0-6	6-12	12-24	24-36	0-6	6-12	12-24	24-36
Lab. No.	2457 38-39	2458	2459	2460	2461	2462	2463	2464	199 39-40	200	201	202
Moisture	3·58	3·66	4·16	4·36	3·49	3·82	4·25	3·89	4·75	5·21	5·23	5·49
Nitrogen	0·052	0·043	0·047	0·045	0·046	0·043	0·044	0·046	0·068	0·031	0·021	0·018
Av. potash	0·022	0·017	0·013	0·0073	0·025	0·021	0·016	0·015	0·025	0·014	0·011	0·012
Av. phos. acid	0·029	0·0175	0·0097	0·0020	0·017	0·013	0·0093	0·010	0·058	0·016	0·0059	0·0035
Clay	33·59	33·37	37·92	36·29	33·43	34·82	37·76	36·89	35·96	37·56	38·25	39·37
Silt	5·71	9·13	8·40	11·76	8·91	9·05	10·18	10·98	11·34	12·24	11·87	12·48
Fine sand	21·51	21·01	23·40	22·19	22·72	23·79	22·41	22·28	20·84	19·08	19·40	17·84
Coarse sand	35·53	36·34	28·09	21·96	34·53	32·32	29·23	28·89	31·57	32·47	32·04	30·11
Acid solubles	3·66	0·15	2·19	7·82	1·41	0·02	0·42	0·96	0·29	..	..	0·20
Max. water holding capacity	47·42	47·67	48·62	51·17	38·69	43·64	41·59	44·12	53·60	52·90	50·56	49·61
pH	8·72	8·46	8·44	8·68	8·96	8·29	8·40	8·08	8·26	8·23	8·51	8·14
Electrical conductivity × 10^5 Mhos	21·96	21·98	25·07	30·73	18·35	20·77	22·82	23·00	19·10	15·00	16·04	17·47

relative humidity during the period of flowering is less, (3) the soil is more fertile and less alkaline, and (4) slightly larger quantity of water is given in the irrigations.

The effect of each of the above factors may now be considered in the light of available literature. Recent work of Ayyar *et al.* [1940] has shown that the effect of large differences in irrigation is negligible on the fibre characters. Hence the slightly increased quantity of irrigation water at Srivilliputhur can hardly be responsible for the large differences observed in the fibre properties. Regarding fertility of soil or manurial treatment on quality of lint produced, fairly good amount of literature is available. The general trend of the conclusions is that the changes in inherent soil fertility or application of manure do not cause much differences in the quality except in very poor soils. Coimbatore soil not being very poor, the fertility factor may not be the cause of the considerable differences observed. It has to be considered that greater solar radiation, higher temperature and lower relative humidity prevailing during the flowering period at Srivilliputhur bring about the changes.

It is well known that heat and light stimulate the growth of a plant, the action being either direct or indirect. Each character has different ranges of temperature favourable for growth and as such the rate of development of a particular character may depend on the rise or fall in temperature up to a certain point [Stiles, 1936]. In the case of cotton, it appears from the present study that the higher temperature (within the range studied) accelerates the rate of length development and the rate of secondary thickening while it retards the sprouting of fibres on the seed and the size of their diameter.

Regarding the number of fibres sprouting on the seed, Balls [1915] has stated that it is influenced by the environment on the day of flowering. Later workers, e.g. Gulati [1930], Ayyar and Ayyangar [1932] and others, have shown that further sprouting of fibres also takes place after the day of flowering. The present results do, however, point out that environment does influence the production of fibres on the seed, the reduction in number being associated with higher temperature, greater solar radiation and lower humidity. By cutting sections of seeds of different ages, from both the places, it is proposed to verify by actual counts whether the number of fibres sprout is less at Srivilliputhur and if so at what stage. Studies in this direction are in progress.

It is of interest to note here that the production of smaller number of fibres per seed is associated with longer length and finer cell diameter.

The differences observed in the foregoing may have been caused by conjoint effects of change of both place and season. By growing the same strains in both places during the same season it would be possible to eliminate the effect of the season. This was done during September to March of 1939-40. It does not mean, however, that the effect of the season is completely eliminated, for the climatic factors are not identical in both the places even during the same season. In fact, the temperature at Srivilliputhur is still higher than that at Coimbatore, though not as much higher as observed before. Five strains were grown at both these places and the differences observed are recorded in the last columns of Table I. It will be seen that the seed weight, lint weight, ginning percentage and number of fibres per seed are significantly higher at Coimbatore. The differences in the other characters are not significant. When these differences are compared with those previously observed, that is, when both place and season are different it will be seen that the variations in lint weight, ginning percentage and number of fibres per seed run parallel, though the magnitude of the difference is less in the present case. This means that the production of fibres on the seed surface is influenced by both place and season. The increased length, reduced fibre weight per cm. and standard fibre weight and improved maturity are, however, caused by the higher temperature and solar activity and not by place.

It was stated above that the reduction of the lint weight and the number of fibres on the seed surface at Srivilliputhur was partly caused by the place. It has been mentioned earlier that even during the same season the temperature at Srivilliputhur is greater. Therefore what is apparently due to the place may be due to the higher temperature. In that case even the smaller variation in temperature appears to influence the production of fibres. That means fibre production on the seed appears to be more sensitive to changes in temperature than fibre length, fineness or thickness development.

Recent work by Anderson [1940] has revealed that the internal temperature of cotton bolls is considerably higher than the atmospheric temperature, when the bolls are exposed to sunlight. It is proposed to study the effect of temperature on the production of fibres on the seed and other fibre properties by examining bolls exposed to sun and those covered from the sun's rays.

At Srivilliputhur the higher temperature is, as already stated, associated with greater quantity of solar radiation. The growing of the plants in a hot-house would eliminate the radiation effect, leaving the temperature effect alone. It would then be possible to state whether the difference produced is caused by the temperature or by the solar radiation. Separation of the

TABLE VII

Variance: mean square and significance

Variance due to	Degrees of freedom	Seed weight in m. gm.	Lint weight in m. gm.	Ginning percentage	Mean length in inch	Fibre weight per cm. 10^{-6} gm.	Unit fibre weight 10^{-6} gm.	Standard fibre weight 10^{-6} gm.	Number of fibres per seed in 1000's	$\sin^{-1}\sqrt{\frac{\text{Mature fibres per cent}}{100}}$	$\sin^{-1}\sqrt{\frac{\text{Immature fibres per cent}}{100}}$
Place	1	540·2 HS	1188·1 HS	297·0 HS	0·1281 HS	0·0554 S	0·4524 S	0·4740 HS	175·14 HS	410·1 HS	243·9 HS
Years	3	190·7 HS	63·0 HS	15·4 HS	0·0058 HS	0·0094 N	0·1418 N	0·0107 N	13·21 HS	49·8 S	31·6 N
Strains	5*	1046·3 HS	144·3 HS	11·4 HS	0·0021 N	0·1404 HS	0·8359 HS	0·0914 HS	9·13 S	30·0 N	36·6 S
Residual	38*	23·82	7·39	0·92	0·00095	0·00837	0·06960	0·00641		12·73	11·26

*For seed weight, lint weight, ginning percentaage and number of fibres per seed the last five strains of Table VIII have been used. Hence for those properties the degrees of freedom for the strains become 4 and for the residual 31

TABLE VIII

Results for seven strains grown at Coimbatore and Srivilliputhur for four years

Cotton		Seed weight in m. gm.		Lint weight in m. gm.		Ginning per cent		Length in inch		Fibre weight /cm. in. 10^{-6}gm.		Unit fibre weight in 10^{-6} gm.		Standard fibre weight 10^{-6}gm.		No. of fibres per seed in 1000's		Mature fibres per cent		Immature fibres per cent	
		Co.*	Sri.*	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.
Co. 2	36–37	134	119	73	59	35	33	0·95	1·05	1·51	1·58	3·65	4·23	1·75	1·57	19·9	13·9	55	70	22	9
	37–38	129	130	71	56	35	30	0·92	1·00	1·62	1·58	3·78	4·01	1·87	1·72	18·8	14·0	50	63	17	19
	38–39	..	121	..	53	..	30	0·92	0·97	1·76	1·64	4·12	4·04	1·91	1·71	..	13·1	60	65	15	13
	39–40	132	136	71	48	35	26	0·92	1·02	1·58	1·56	3·70	4·03	1·81	1·65	19·2	11·9	53	60	18	11
3915 F	36–37	108	114	64	52	37	31	0·90	1·11	1·23	1·29	2·82	3·64	1·51	1·38	22·6	14·3	50	61	27	14
	37–38	109	122	69	59	39	33	0·93	1·00	1·36	1·22	3·22	3·09	1·59	1·41	21·5	19·0	51	55	20	25
	38–39	116	125	68	60	37	32	0·90	1·14	1·40	1·37	3·19	3·96	1·67	1·32	21·3	15·2	53	75	25	8
	39–40	120	128	69	56	36	30	0·95	1·06	1·27	1·50	3·06	4·06	1·51	1·51	22·4	13·8	50	75	22	6
3915 Q	36–37	104	117	62	52	37	31	0·93	1·09	1·41	1·25	3·33	3·45	1·65	1·30	18·6	15·1	55	65	24	13
	37–38	107	114	66	52	38	32	0·91	1·01	1·33	1·16	3·16	3·10	1·61	1·41	21·6	17·4	51	55	23	28
	38–39	114	118	68	56	37	32	0·92	1·03	1·32	1·27	3·09	3·34	1·48	1·28	22·2	16·6	57	70	20	11
	39–40	112	127	65	53	37	29	0·91	1·04	1·31	1·47	3·02	3·88	1·58	1·49	21·6	13·7	49	66	23	9
4456	36–37	93	109	55	46	37	30	0·92	1·05	1·36	1·28	3·18	3·40	1·65	1·43	17·3	13·5	49	56	24	17
	37–38	92	92	58	48	38	34	0·92	0·93	1·26	1·18	2·95	2·69	1·48	1·34	19·7	17·8	52	57	22	21
	38–39	106	104	61	46	36	31	0·91	1·04	1·42	1·20	3·27	3·19	1·70	1·33	18·7	14·4	48	58	21	17
	39–40	99	106	56	46	36	30	0·90	1·00	1·07	1·34	2·45	3·42	1·57	1·46	21·9	13·5	29	59	33	15
4463	36–37	118	135	59	56	33	29	0·97	1·07	1·64	1·37	4·05	3·72	1·70	1·47	14·5	15·1	65	59	12	12
	37–38	126	122	76	63	38	34	0·95	1·00	1·57	1·46	3·71	3·55	1·74	1·53	20·2	17·0	56	65	16	14
	38–39	134	134	71	58	34	30	0·95	1·04	1·61	1·32	3·89	3·48	1·76	1·37	18·3	16·7	58	66	15	13
	39–40	123	121	68	50	36	29	0·94	1·03	1·63	1·46	3·89	3·84	1·94	1·50	17·5	13·0	45	64	17	9
4466	36–37	116	131	58	54	33	28	0·97	1·08	1·50	1·40	3·70	3·86	1·55	1·43	15·7	14·1	67	66	13	11
	37–38	122	125	65	56	35	31	0·92	0·97	1·50	1·39	3·54	3·44	1·67	1·59	18·4	16·0	56	57	16	19
	38–39	130	141	65	56	33	29	0·90	0·99	1·62	1·47	3·69	3·70	1·72	1·56	17·6	15·1	62	61	13	13
	39–40	127	138	68	54	35	28	0·91	0·98	1·51	1·40	3·48	3·48	1·67	1·56	18·9	15·5	41	53	20	14

*Co. = Coimbatore Sri. = Srivilliputhur

TABLE IX

Mean weekly relative humidity (per cent) and temperature (°F.)

No. of weeks after sowing	Relative humidity								Temperature							
	Coimbatore (September to April)				Srivilliputhur (March to August)				Coimbatore (September to April)				Srivilliputhur (March to August)			
	1937-38	1938-39	1939-40	Mean	1938	1939	1940	Mean	1937-38	1938-39	1939-40	Mean	1938	1939	1940	Mean
1	73·0	72·4		72·7	68·1			68·1	77·1	80·2		78·6	87·3			87·3
2	63·4	68·1	70·8	67·3	67·5		69·7	68·6	79·1	80·7	76·8	78·9	87·5		82·2	84·8
3	66·7	79·7	70·6	72·1	70·4		62·8	66·6	79·0	77·5	80·8	79·1	86·4		84·9	85·6
4	67·3	70·2	66·0	67·7	73·6	51·8	68·2	64·7	79·0	78·5	80·4	79·3	88·4	86·8	83·6	86·3
5	81·9	69·8	70·8	74·2	70·4	60·9	55·6	62·2	75·5	79·3	80·2	78·3	87·3	86·4	85·4	86·4
6	74·6	67·3	77·8	73·4	70·9	64·6	68·3	68·0	76·4	78·8	79·6	78·3	91·2	85·0	83·8	86·7
7	71·3	67·7	77·4	72·0	66·3	...	68·9	67·4	77·3	81·1	79·5	79·3	90·6	...	84·8	87·7
8	68·2	76·0	80·4	74·8	65·1	72·3	74·8	71·7	77·3	77·8	78·3	77·8	90·9	84·0	79·9	84·9
9	80·1	77·2	77·8	78·3	68·3	71·7	77·3	72·3	76·5	75·8	79·7	77·3	91·7	88·7	80·8	87·1
10	81·3	70·8	83·5	78·8	70·2	72·8	71·2	71·3	73·2	77·1	77·3	75·9	88·4	86·3	84·2	86·3
11	79·1	62·8	81·8	74·5	64·4	57·5	66·4	62·6	75·5	77·5	78·3	77·1	86·4	89·8	84·6	86·9
12	82·7	67·7	84·8	78·5	63·6	60·7	63·0	62·6	74·2	76·7	76·8	75·9	86·3	90·3	86·6	87·7
13	80·8	66·3	74·7	74·0	66·8	61·9	59·9	62·9	73·1	77·7	77·0	75·9	86·8	89·4	87·8	88·0
14	70·2	69·0	72·0	70·3	67·0	60·7	66·0	64·6	72·6	75·8	76·5	74·9	83·4	86·8	87·3	85·8
15	69·3	65·5	67·3	67·3	63·0	62·8	73·1	66·3	70·9	76·7	75·2	74·3	84·2	86·7	84·7	85·2
16	68·2	64·8	68·1	67·0	77·2	55·3	61·7	64·7	74·1	75·2	75·2	74·8	84·8	88·6	85·3	86·2
17	68·3	74·0	64·3	68·8	80·4	61·3	57·8	66·4	75·3	73·2	75·1	74·5	85·9	86·4	83·9	85·4
18	63·1	56·6	62·7	60·8	64·3	58·3	63·3	61·9	72·8	73·5	72·8	73·0	82·6	87·6	84·8	85·0
19	66·8	74·8	64·3	68·7	77·6	58·7	63·7	64·1	74·9	75·2	75·5	75·2	81·5	87·2	83·5	84·1
20	63·2	68·6	63·8	65·1	66·0	57·8	65·7	63·2	74·3	73·8	74·2	74·1	85·5	88·8	83·0	85·7
21	59·3	65·4	59·6	61·3		60·5	62·9	61·7	74·2	75·2	71·8	73·7	82·6	90·3	83·8	85·6
22	60·2	57·5	61·7	59·7		62·1	59·7	60·9	75·7	76·7	75·6	76·0	83·9	89·2	84·8	86·0
23	70·0	54·8	61·3	62·0		74·3	64·7	69·5	78·1	76·7	76·7	77·2		83·7	81·8	82·8
24	70·0	60·2	60·3	63·5		62·7	66·3	64·5	79·2	78·5	78·7	78·8		86·5	81·3	83·9
25	62·1	54·8	56·7	57·8					78·4	81·0	79·0	79·5				
26	57·0	49·9	51·5	53·1					80·3	80·2	79·9	80·1				
27	58·2	56·5	50·7	55·1					82·7	83·0	79·6	81·8				
28	52·1	68·0	58·2	59·4					83·1	81·6	80·0	81·6				
29	60·2	59·4	59·2	59·5					80·3	81·9	81·2	81·1				
30	67·1	52·8	57·7	59·2					82·7	82·7	81·7	82·4				
31		64·5	53·8	59·2						84·8	83·2	84·0				

two factors is important in view of the fact mentioned by Stiles [1936]—' marked response to changes in temperature has been observed with a few plants, but in general, temperature appears to play a much smaller part as a stimulus than light and gravity '. But absence of facilities stands in the way of this enquiry.

Conclusion

The following points are revealed by the present study :

(1) At Srivilliputhur the fibres are longer, finer, more mature but lesser in number on the seed than at Coimbatore.

(2) The maturation period of the boll and the lengthening and thickening phases of the fibre are less at Srivilliputhur.

(3) The rate of length development and that of the secondary wall deposit are higher at this place.

(4) The improved length and fineness of the fibres and the reduction in their numbers per seed at Srivilliputhur appear to be caused by the higher temperature and solar radiation at this place.

Acknowledgements

The writer wishes to place on record his deep indebtedness to Rao Bahadur V. Ramanatha Ayyar for his advice, sustained help and sympathetic interest in the work. To Dr Nazir Ahmad he is grateful for many helpful suggestions, for the photographs of Plate XIX and for the loan of the thermohygrograph. His thanks are due to the assistants and fieldmen of the Cotton Specialist's Section, Coimbatore, for their help and to the Government Agricultural Chemist, Coimbatore, for the analysis of the soils. To Mr A. N. Gulati and Dr N. Krishnaswami he is indebted for advice in the technique of the preparation of sections. The work was carried out under the financial aid of the Indian Central Cotton Committee.

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Appendix

The longitudinal section of a seed is more or less like the figure A, B, C, D (Fig. 4). As a first approximation the curved lines AB and AD may be replaced by straight lines AB and AD respectively. The perimeter then becomes the two sides of an isosceles triangle ABD plus the semi-circumference BCD. The surface of the seed is the surface of rotation when ABC revolves

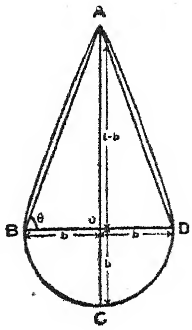

Fig. 4

round the axis AC; that is, the slanting face of a cone with base of diameter BD and slant height AB plus semispherical surface of diameter BD. If $2b$ is the breadth of the ovule, BD, and θ the angle ABD the surface area of the seed may be expressed as $\pi b . b \sec\theta + 2\pi b^2$

$$= \pi b\,(b \sec\theta + 2b) \ldots\ldots\ldots\ldots \text{(1)}$$

If l is the length of the ovule, AC, then

$$\sec\theta = \frac{\sqrt{(l-b)^2+b^2}}{b}$$

so that (1) becomes $= \pi b\left\{\sqrt{(l-b)^2+b^2}+2b\right\} \ldots$ (2)

The perimeter of the section is 2 AB + semi-circumference BCD = $2b \sec\theta + \pi b$

$$= 2\sqrt{(l-b)^2+b^2} + \pi b$$

If we assume this section to have a thickness of d, equal to the diameter of a fibre of that section, then the surface area of the seed on which the fibres sprout will be given by $d\left\{2\sqrt{(l-b)^2+b^2}+\pi b\right\}$ .... (3)

The number of fibres produced on this section as counted may be called n. Then the total number on the whole surface becomes from,

$$\text{(2) and (3)} = \frac{\pi b\left\{\sqrt{(l-b)^2+b^2}+2b\right\}}{d\left\{2\sqrt{(l-b)^2+b^2}+\pi\right\}}\, n \ldots\ldots \text{(4)}$$

RESEARCH NOTE

A PRELIMINARY NOTE ON THE USE OF SOME COMMON INDIAN FRUITS AND VEGETABLES IN MAKING JELLIES

By P. G. Krishna, Ph.D., Agricultural Chemist, Hyderabad, Deccan

(Received for publication on 9 June 1943)

Around Hyderabad city it has been a common practice for some decades of making jellies from guavas and wood apple. In making jelly with guavas four to six tablespoons of lemon juice is added to each quart of extracted juice from mature but not fully ripe guavas while the wood apple jelly is made without the addition of lemon juice.

For the past two years some work in the use of custard apple fruit in making jams and jellies has been in progress and during this time other common fruits and vegetables have also been investigated in this connection. It was found that many common fruits and vegetables are better suited for jellying being richer in pectin content than the custard apple fruit.

As a result of the work that has been done so far it might be stated that unripe but mature mango, wood apple and *ambada* (*Hibiscus cannabinus*) (red and white variety) form very satisfactory material for making jellies, being quite rich in both pectin and acid. The jellies are clear and have varying sparkling colours which keep well over several months. Guavas, *ber*, *ballar*, etc. make satisfactory jellies with the addition of required acid and have attractive colours and also keep well. But in the case of those requiring acid, the fruit flavour is usually not quite prominent as the lemon juice added gives the lemon taste and flavour.

Tamarind seed, *ber* seed and some millets also have considerable amounts of pectin but jellying even with the required acid is not satisfactory. Investigations with these and other fruits and vegetables are in progress.

PLANT QUARANTINE NOTIFICATION

Notification No. F. 16-5 (1)/43-A., dated 10th May 1943 of the Government of India in the Department of Education, Health and Lands.

In exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make the following order for the purpose of prohibiting, regulating and restricting the import of live fungi into British India ;

1. In this order, 'fungus' means any living fungus in culture media or on living plants or any fungus spores or mycelium intended to be so cultured, but excludes dried specimens not intended to be so used.

2. No fungus shall be imported into British India unless—

(a) it is consigned to the Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi, or

(b) it is accompanied by a special permit, in accordance with the form set forth in the Schedule to this order, authorizing such importation issued by the Imperial Mycologist :

Provided that a permit shall not be refused in respect of any fungus which is not, in the opinion of the Imperial Mycologist, likely to cause infection to any crop.

3. This order shall come into force with effect from 1 September 1943.

SCHEDULE.

Form of special permit authorizing importation of living fungi in pure culture.

1. Name, designation, and full address of the importer ....
2. Name of the fungus to be imported........
3. Country from which importation is sought..............................
4. Whether importation is intended by sea, land or air.........................
5. Whether in its original home the fungus is a parasite, and if so, the name of the host plant..........................
6. Name, designation and address of the exporter............................
7. Purpose of importation ....

The above information is true to the best of belief.

Date.......... (Signature of the importer).

I authorize the importation. This permit will be valid up to................................

Date............... (Signature of Imperial Mycologist).

[*N.B.*—The permit must be obtained in advance of sending the order. The tubes or other container of the fungus must be clearly and distinctly marked with the name of the fungus, which should agree with the name on the import permit].

ERRATUM

The Indian Journal of Agricultural Science,

Vol. XIII, Part III, June 1943,

Page 321, column 1, line 16, *for* '15 April 1943' *read* '15 May 1943'.

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CONTENTS

VOL. XIII, PART VI

(December 1943

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal

ORIGINAL ARTICLES

WHEAT GRAIN—CHANGES IN ITS COMPOSITION

By J. Walter Leather, Ph.D., F.I.C., F.C.S., Formerly Imperial Agricultural Chemist

(Received for publication on 13 October 1943)

(With one text-figure)

(The following paper on wheat grain written by the late Dr J. W. Leather has been found in the records of the Chemical Section of the Imperial Agricultural Research Institute. Dr Leather's intention was to publish it as a Memoir of the Imperial Department of Agriculture in India, but evidently this could not be carried out before his departure on Military duty during the last Great War and subsequent retirement. In view of the originality of thought and work which anticipated modern trend of research in soil and plant chemistry, it is but fitting that the author should be given credit for the pioneering thought and work by publishing the article in the form in which it was written in Dr Leather's own hand over 30 years ago. The paper is illustrated by a photographic copy of a sheet on which seeds of crops discussed were pasted by Dr Leather.—B. Viswa Nath.)

During the last two or three years several papers have been published showing that the composition of wheat is subject to changes which have been referred to effects of soil or manure, or both.

Hall [1904-5] quotes analyses of flour derived from wheat grown on the Rothamsted and Woburn plots, which exhibits differences in the amounts of total nitrogen and gluten, though no very simple relationship between the nature of the manure and the composition of the flour is discernible, and indeed the differences are only small; the crops were, however, harvested in bad weather.

Le Clerc [1906] produces evidence of the influence which several factors have been found to exert on the amount of nitrogen in the grain and on the weight of the seed. Durum wheat grown in arid or semi-arid states contained about 2·8 per cent nitrogen against 2·2 in that produced in humid or irrigated states. Similarly Durum wheats which matured in a short growing period (100 days or less) contained about 2·8 per cent nitrogen against 2·45 per cent in those which required 130 to 250 days.

The effect which varying proportions of lime and magnesia in soils have on the quality of wheat and barley is referred to by Voelcker [1907] who has found that as the relative proportions of lime and magnesia in a soil approach nearer and nearer to the ratio 1 : 1 so the wheat grain tends to become more and more glutinous or 'hard', in other words to show more 'strength'.

Some changes in the composition of wheat having been observed in experiments at Pusa, a brief note on them will be of interest.

For the purpose of some pot-culture experiments, my colleague Mr A. Howard very kindly provided me with a few ears of hard-grey Gangajali wheat, which was sown in jars of local soil, some of which were unmanured whilst to others fertilizers were added. When the produce was harvested, the grain was found to vary considerably in appearance; that which had been grown with the aid of some fertilizers having become very starchy in appearance. The effect was quite uniform throughout the series of cultivations and was so striking that it was decided to make a check experiment during the following season (1907-08). In this experiment some of the 'glutinous' seed which had been obtained from unmanured soil, and some of the 'starchy' seed from soil which had been manured with calcium cyanamide and phosphate, were each grown (*a*) without manure and (*b*) with the aid of oil-cake and superphosphate in order to ascertain whether the changes which had occurred in 1906-07 could be reversed. At harvest this was found to have occurred, and the produce has been analysed, in so far as the material sufficed for the purpose.

Before considering the composition of the grain which is set out in the subjoined statement it will be convenient to mention the chief details regarding the cultivations. The soil employed, that of this Institute, is a highly calcareous one containing upwards of 40 per cent $CaCO_3$; like all soils of the Indo-Gangetic alluvium the amount of organic carbon and organic nitrogen are very small; organic carbon=0·4 per cent, and organic nitrogen=0·05 per cent; the amount of phosphate in a readily assimilable condition is unusually small and addition of superphosphate has a marked effect on all crops, but addition of potash manures does not increase the yield. It is an extremely fine soil even for the alluvium, the particles of 75 per cent of it measuring less than 0·05 mm. and 98 per cent less than 0·15 mm., in diameter, and it holds about 25 lb. of water per cubic foot after drainage has ceased at the conclusion of the monsoon. Excepting then for

a deficiency of organic nitrogen and phosphate, it is an unusually fertile soil.

Both the proportion of moisture in the soil and the nature of the nitrogenous fertilizers employed have differed in the several experiments. They are indicated against each specimen in the accompanying statement and it seems certain that the results obtained cannot be referred to any one of these factors in particular. The effect of nitrogenous manure alone is the same whether a nitrate, or calcium cyanamide or oil-cake is employed; and a corresponding remark applies to the proportion of water in the soil.

An examination of the statement shows how the proportion of nitrogen fell, and the starch increased, when grown in soil liberally manured with a nitrogen compound and phosphate, whilst when the phosphate was omitted the reverse effect was produced. Grown without manure the composition of the grain showed but little change.

Passing to the results of the second year's cultures, it is seen that from the seed grown without manure in 1906-07, a grain of higher nitrogen content was obtained without manure, whilst with the aid of oil-cake and superphosphate a grain of low protein and high starch content was produced. Similarly from the 'starchy' grain produced by the aid of manure in 1906-07, a high nitrogenous grain was obtained without manure, and a 'starchy' one with the aid of oil-cake and superphosphate. That is to say, the change in composition was obtained at will. The amount of seed obtained from some of the jars (those without manure or with nitrogen only) was only small and was too small to admit of both the nitrogen and starch being determined.

These results are interesting both because they are some of the most definite on record, and also because they draw attention to the fact, now becoming more generally recognized, that the character of a soil and its treatment may occasion marked changes in the composition of the produce.

The wheats were grown under circumstances somewhat different from those generally obtained in the field, and it is not suggested that the effects of manures would there be so marked as in pot-cultures, but the general importance of the subject can hardly be over-estimated, and illustrates both the advantage of combining chemical investigation with botanical selection, and also the possible effect which the nature of the soil may have on the composition of at least the fruit of plants.

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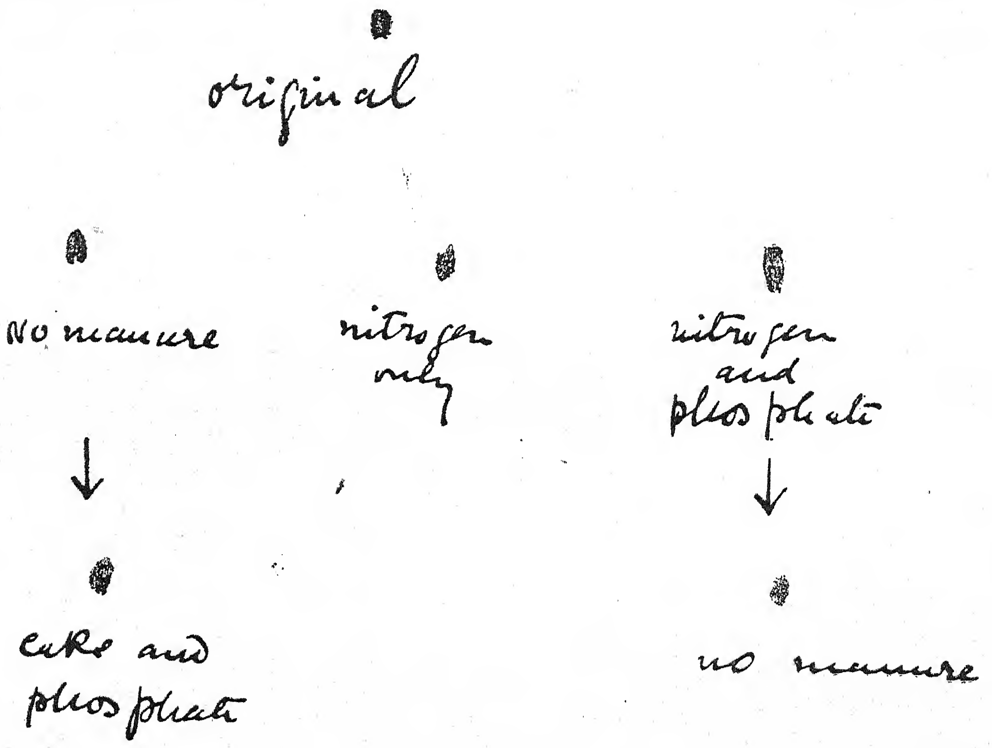

FIG. 1. Seeds of crops

Statement showing the composition of wheat (whole grain)

	Weight of 100 seeds	Nitrogen percentage	Starch percentage
Original seed	3·5	2·57	50·90

Jar No.	Soil moisture per cent	1906-07 Manure	Nitrogen per cent	Starch per cent	Weight of 100 seeds gm.
101	10	Nil			
401	10	Nil			
105	15	Nil	2·85	49·55	2·5
405	15	Nii			
409	20	Nil	2·46	...	2·9
102	10	Calcium nitrate			
402	10	Cal. cyanamide	4·44	40·59	2·1
106	15	Calcium nitrate	(4·445)		
406	15	Calcium cyanamide			
403	10	Cal. cyanamide and superphosphate	1·56 (1·53)	56·61	4·3
407	15	Do.	1·72 (1·69)	58·29	3·9
411	20	Do.	1·56	...	4·3
404	10	Cal. cyanamide, superphosphate and sulphate of potash	1·87 (1·83)	55·88	3·8
408	15	Do.	1·71 (1·74)	54·96	4·0
Derivative of 409					
403	20	Nil	3·19	...	2·6
404	20	Oilcake and superphosphate	1·54 (1·56)	58·87	3·6
Derivative of 411					
401	20	Nil	3·26	...	2·3
402	20	Oilcake and superphosphate	1·84 (1·87)	57·10	3·3

Change in the nitrogen and starch contents of grain by manuring

Manures N at 50 mg. per kilo as $Ca(NO_3)_2$ } in jars of 15 kilos capacity
P at 100 mg. per kilo as super.
K at 50 mg. per kilo as K_2SO_4

N was determined by Kjeldahl method; starch by Sullivan's method using malt diastase

Soil	Crop	Treatment	Percentage on dry substance N	Starch
Shillong	Maize	Nil	1·98	58·1
Do.	Do.	N	2·52	54·7
Do.	Do.	N+P	1·73	61·6
Do.	Do.	N+P (duplicate pot)	1·83	61·4
Do.	Do.	N+P+K	1·94	60·2
Do.	Do.	N+P+K (Duplicate).	1·97	59·1
Akola	Maize	N	2·32	55·8
Do.	Do.	N+P	1·96	58·2
Do.	Do.	N+P+K	1·57	60·7
Palur	Maize	Nil	2·05	56·0
Do.	Do.	N	1·75	58·5
Do.	Do.	N+P	1·96	57·5
Do.	Do.	N+P+K	2·06	57·2
Pusa	Kodo	Nil	0·87	51·4
Do.	Do.	N	1·05	50·1
Do.	Do.	N+P	0·92	50·9
Pusa	Marva	Nil	1·32	59·3
Do.	Do.	N	1·96	56·3
Do.	Do.	N+P	1·23	62·3
Do.	Do.	N+P	1·31	58·8
Pusa	Rice	Nil	1·22	56·4
Do.	Do.	N	1·63	54·9
Do.	Do.	N+P	1·17	57·5

SOILS OF THE DECCAN CANALS

V. INVESTIGATIONS INTO THE CAUSES OF SOIL DETERIORATION UNDER INTENSIVE SYSTEM OF SUGARCANE GROWING, WITH SPECIAL REFERENCE TO THE CHANGES IN THE PHYSICO-CHEMICAL PROPERTIES OF THE SOIL: SOIL FERTILITY SURVEY ON THE NIRA LEFT BANK AND GODAVARI CANALS

By J. K. Basu, M.Sc. (Cal.), Ph.D. (Lond.), F.N.I., Soil Physicist, Sugarcane Research Scheme for Deccan, Padegaon* and V. D. Tagare, B.Sc., B.Ag. (Bom.), Graduate Assistant

(Received for publication on 22 May 1943)

(With six text-figures)

Since the introduction of canal irrigation in the Bombay-Deccan, sugarcane has occupied the most important place among the crops grown in this tract. The rapid growth of the sugar factories in the province has given further impetus to sugarcane cultivation, and at the present moment the concentration of cane cultivation on the canals has almost reached its limit. Striking improvements in cultural methods coupled with the breeding of superior varieties are bringing forth phenomenal yields, and it has become a matter of the greatest concern for the well-being of the society to know whether this type of intensive agricultural practice is going to conserve the fertility of the land for long. Unfortunately soil deterioration—apart from the question of water logging and salt efflorescence—being a slow process, there is no available means of assessing soil changes under a short period of cropping. It was for this reason thought desirable to undertake a detailed fertility survey of the soils of the older canals where sugarcane has been grown for a number of years. The Nira Left Bank and Godavari Canals afforded excellent opportunity for such studies where soils were brought under irrigation for a fairly long time. In spite of certain inherent difficulties in this kind of survey it will be seen that these investigations have thrown considerable light on the problem, and have indicated in a general way the probable causes of soil deterioration and the lines in which further researches can profitably be pursued. It may be worthwhile pointing out in this connection that the value of this work has further been enhanced by corroboration of some of these results in a series of farm experiments under controlled conditions which are running for the last 10 years in succession. The results of these farm experiments will be dealt with in separate papers. The object of the present study is (*i*) to examine critically the past history of the sugarcane soils with a view to trace the causes of deterioration or otherwise of soils under the cultivators' systems of cane-growing, (*ii*) to study the changes in soil properties under long continued cane cultivation, and (*iii*) to correlate soil properties with soil fertility so as to arrive at an understanding of the significance of the soil factors which contribute to the fertility of sugarcane soils.

Survey technique

For the purpose of collecting information, only reliable and intelligent cultivators were approached who could supply the previous history of their plots for a number of years. It may be explained that as the cultivation of of sugarcane requires considerable outlay and incidental expenditure, it has to a large extent assumed the nature of commercialized farming in the Deccan, and even the average farmers in the canal areas are of a more progressive type than those in the less developed areas. The accounts of *gul* produced and manure applied for certain old plots are available with some of the advanced cultivators, and from Irrigation Departmental records it is possible to verify approximately the number of years certain survey numbers have been brought under cane cultivation. Consequently the collection of such information was less difficult than would be expected on ordinary non-cane farms. Attempts were made to get information on the following points:

(*i*) Manurial history,
(*ii*) Yields of sugarcane or *gul*,
(*iii*) System of rotations practised,
(*iv*) Cultural operations usually followed,
(*v*) Approximate quantity of irrigation water applied,
(*vi*) Nature of drainage and other subsoil conditions,
(*vii*) Typical weeds, and
(*viii*) Other informations if any.

The soils were then grouped into two classes, deteriorating and non-deteriorating, the criterion being the calculated quantity of nitrogen

*This scheme is partly subsidized by the Imperial Council of Agricultural Research

required to produce a 40-ton crop of cane per acre in successive periods.

Surface soil (0-12 in. deep) samples were collected from such representative plots of which the above information was available, samples being made composite of six to ten random samples taken over the entire plot depending upon the shape and size of the plot. In order to compare the effect of irrigation and cane-growing on the soil changes similar soil samples were also collected from a fallow or a dry plot near the cane plot which was never under irrigation and represented as far as possible identical soil and subsoil conditions. Wherever possible soil samples were also collected separately from eight months' blocks where other irrigated crops but cane have been taken previously.

The results of the survey are described below:

(A) Old canal—Nira Left Bank Canal,

(B) Moderately old canals—Godavari Canals,

(C) Soil factors responsible for fertility of surgarcane soils.

Presentation of data

(A) *The Nira Left Bank Canal*

This canal was opened in 1885 but the cane cultivation did not spread much till the year 1892 when the area under cane reached over 1,600 acres, the main crops under irrigation prior to this year being wheat, *jowar*, *bajri* and to a certain extent groundnut. The area under cane, however, began to increase rapidly from this year and rose to a figure of over 4,000 acres by 1894, and by 1903 the acreage under cane was well over 8,000. The Saswad *Malis* who took the land on lease, having no permanent interest in the land began to exploit it to the maximum extent, and in order to raise a bumper crop they began to use very heavily irrigation which soon resulted in extensive soil damage in the form of waterlogging and salt efflorescence. These damaged lands had to be left out of cultivation and new lands acquired until the fully damaged lands formed 22 per cent of the total cultivable area in 1925, and 34 per cent by 1930 on this canal [Inglis and Gokhale, 1934]. In spite of these disasters the acreage under cane rose to near about 14,000 by 1927-28, and cane cultivation became a well-established practice on this canal from this time onwards.

Apart from the above-mentioned damages due to waterlogging and salts there were reasons to believe that certain soils were actually 'losing heart due to intensive cane cultivation, and more and more manures were required to be put in these soils every year to secure their former yields. In the discussions that follow only this type of soil deterioration will be considered.

Behaviour of cane soils. Seventeen cane soils have been selected from various representative places from the whole length of the Nira Left Bank Canal whose complete history is known. From the previous history, it has been possible to classify these soils under two groups from the point of view of fertility: (*a*) soils which are either improving or remaining stationary, i.e. non-deteriorating, and (*b*) soils which are deteriorating. These are shown by arrows in Fig. 1. In this graph the soils have been arranged in order of descending fertility, this being calculated as number of tons of canes produced per 100 lb. of nitrogen. Other information such as soil depth, actual yields of cane and manures applied, and some important soil properties are also shown graphically against the soil numbers. It will be evident that the more fertile soils are not deteriorating with the exception of one soil, e.g. No. 45. It will be also noticed that generally speaking the shallower types of soils fall under group (*a*) whereas the heavier soils fall under (*b*) under the existing systems of irrigation in agriculture.

Generally there are four major factors which affect soil fertility, and are responsible for the deterioration or otherwise of soils. They are—(*i*) quantity of irrigation water, (*ii*) tillage operations, (*iii*) manuring and (iv) crop rotations.

(*i*) Since the quantities of irrigation water are never measured by the cultivators, nothing definite can be said about the quantity of water used in cane cultivation excepting the fact that there is a general tendency among the cultivators of over-irrigating (water being charged on acre basis) rather than under irrigating their plots. The dose of water may work up to 140 to 160 acre-inches in most cases.

(*ii*) The cultural operations for cane are not very dissimilar, the usual practice being three ploughings by iron plough, ridging, weeding, inter-culturing and earthing up. Prior to 1909 wooden ploughs were universally used.

(*iii*) About manuring more definite information is available. General trend in the present-day manuring is to diminish the doses of nitrogen, bulk of the reduction falling on the quantities of farmyard manure used. A striking feature of the change consists in the introduction of sulphate of ammonia during the last decade. With the data available at our disposal it is hardly possible to say any thing definite about the efficacy of this change-over in the manuring. However, there are evidences of a beneficial effect of this mixed manuring (i.e. mixture of inorganic and organic nitrogen) in deep soils.

(*iv*) History regarding crop rotations in these soils is fairly reliable and we shall discuss now the merits of these rotations in different soils. In a shallow ($<$2 ft. deep), well-drained soil a three-

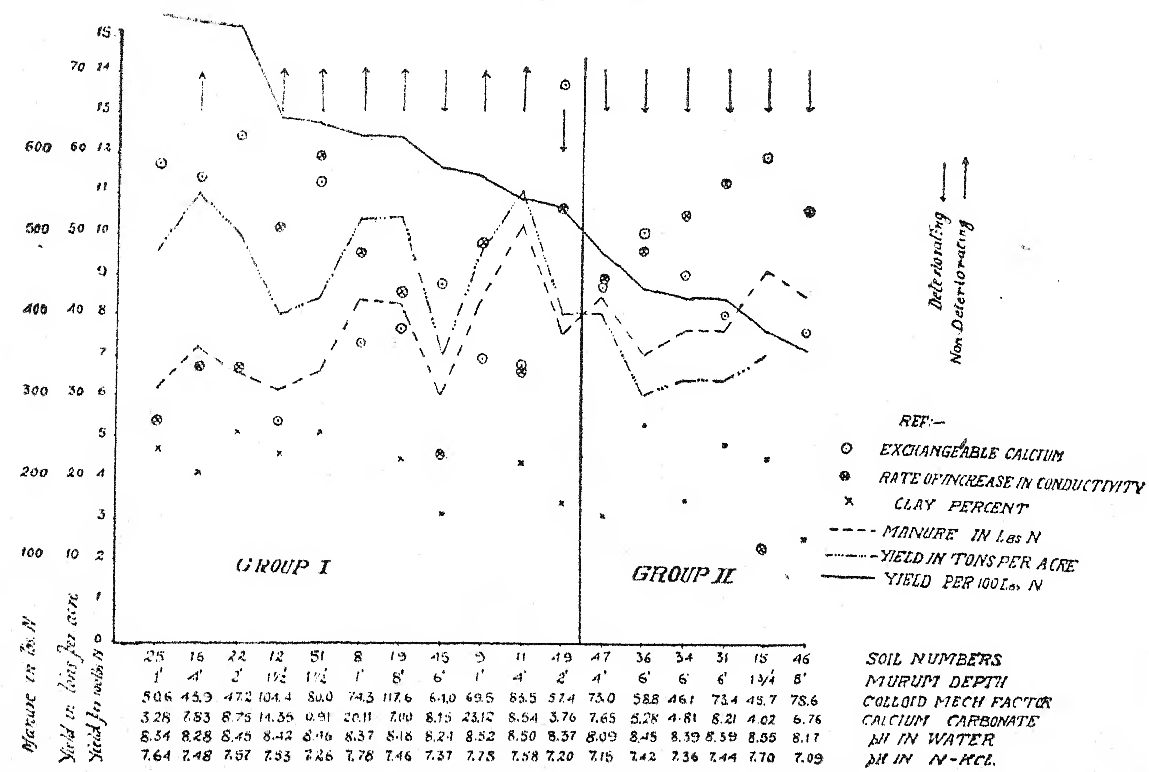

FIG. 1. Soil fertility in relation to physico-chemical properties of soils. N.L.B.C.

year rotation of cane—cotton—*rabi jowar or* cane—rice and gram—*jowar or bajri* (No. 12) has proved successful in improving the fertility of the soil. Even a two-year rotation of cane—*bajri* (Nos. 8 and 9) or cane—$\frac{\text{cotton and gram}}{\text{or wheat}}$ (No. 51) has proved beneficial. Exhausting rotation such as cane ratoon—*bajri* or *jowar* or rice (No. 49) has been found distinctly harmful in the long run. The actual significance of this is shown in Fig. 2. It will be evident that in the rotation cane—rice and gram—*jowar or bajri* the soil gets a rest for 10 months during three years as contrasted with the cane—ratoon—cotton, where only five months' fallow is observed during the same period. If we take cane, ratoon, cotton and rice (because of the impounding water) as exhausting crops we find that under the first rotation the soil is under exhausting crops for only 17½ months as compared with 31 months out of a total of 36 months in the case of the second rotation. From this point of view cane—*bajri* rotation is also much better than cane—ratoon—cotton.

In the case of deep soils (> 4 ft.) all the soils are showing signs of deterioration excepting the soil No. 19 where a four-year rotation of *jowar*—*bajri*—rice—cane has improved the fertility status of the soil. Two-year rotation of cane—cotton or *bajri* or rice (Nos. 45 and 46) has definitely proved harmful while even a three-year rotation of cane—*jowar*—*jowar* (No. 31) has not been able to retain the fertility of a deep soil. Fig. 2 illustrates the advantage of a four-year rotation over a two-year rotation of cane—cotton. There is thus 23½ months of fallow out of 48 months in the first case as compared with five months out of 24 months in the latter case. The periods occupied by the exhausting crops are 17½ out of 48 and 19 out of 24 months respectively. Hence a four-year rotation in heavy soil appears to be quite essential so as to allow sufficient period of rest for recuperation.

Effect of cane growing on soil properties

Some of the characteristic soil properties and the effect of cane growing on these properties are discussed below. These are illustrated in Figs. 1 and 3.

Exchangeable calcium. This property has been determined according to the method of Crowther and Basu [1931]. The proportion of exchange calcium in the colloidal complex determines soil structure and other associated physical properties. A soil which contains a high percentage of this

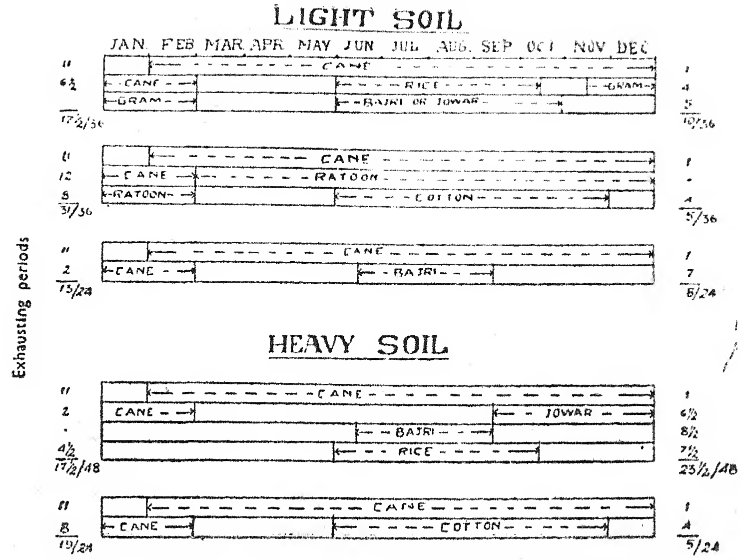

FIG. 2. Effectiveness of different rotations in light and heavy soils
(Soil fertility survey)

base is thus most beneficial to crop growth. This is fairly high in most of the soils and reflects in a general way the potential fertility of the soils. It is of particular interest to note that generally the shallower soils (which in majority of cases are non-deteriorating) are richer in calcium colloids than the deeper ones the average figures being 50·86 and 42·41 m.e. per cent respectively.

Generally speaking this soil property is improved as a result of cane-growing. Thus there has been increase in exchange calcium in cane plots over the corresponding plots without cane, in 8 cases, and decrease in 2 out of 14 cases, the increases being more pronounced when comparisons are made between cane plots on the one hand, and the fallow and dry cultivated on the other. The average of 14 pairs shows an increase of about 9 per cent over the control non-cane plots, non-deteriorating soils showing greater increases.

Rate of increase in electrical conductivity of soil solution. Sen and Wright [1931] have shown that the rate of increase in electrical conductivity is an indication of the relative fertility of soils. Our results show that the rate of increase in electrical conductivity is correlated more closely with the amount of manures applied than with the fertility status of different soils as indicated by yields of cane per unit nitrogen. This will be clear from Fig. 1. It is probable that the micro-organic activity is increased by heavy manuring (organic) in cane plots thus causing proportionately increased rate of electrical conductivity. Thus it is likely that this method will prove useful as a measure of the residual effect of heavy manuring in cane soils. In majority of cases (i.e. 10 out of 14) the value has gone up in the cane plots over the control. It is, however, noted that non-deteriorating soils show greater increases than the deteriorating ones, the average increases being 30·91 and 20·07 respectively.

Total soluble salts. Soluble salts present in soils have been determined by conductometric method using L and N Soil Bridge [Davis, 1927]. The values of soluble salts in these cane soils are usually less than 0.5 per cent with the exception of soil No. 45 which has got 0.93 per cent and is showing signs of deterioration. This value has increased in seven cases and diminished in six cases by cane-growing although the average value shows a slight fall. When only the fallow plots are compared with cane plots we find that total salts are lowered by cane-growing in every case.

Soil reaction. This property has been determined by quinhydrone method using Veibel electrode [Biilmann, 1924] and checked occasionally by the colorometric method. The pH in water varies between 8.09 to 8·55 while the NKCl pH gives a range of 7.09 to 7.78. As a result of cane-growing the pH value in water has gone down in eight cases and remained stationary in five cases. Only in one case the value has gone up. pH value in NKCl has gone down only in five cases. The average values in both determinations show a slight lowering.

Calcium carbonate. This is determined by the Scheibler's Calcimeter as described in a previous

publication [1938]. All the soils are well supplied with calcium carbonate with the exception of soil No. 51 which contains less than one per cent. Loss of this soil constituent has taken place by growing cane under canal irrigation in 12 cases out of a total of 14. If the average is worked out over all the pairs of plots it comes to a net loss of about 1.7 per cent or 30 tons per acre foot of soil during the entire period of cane-growing.

Exchangeable sodium. This property has been determined by electrodialysis [Basu, 1931]. The values vary between 0·48 to 1·16 m.e. per cent in irrigated plots while in dry plots values as high as 6.95 m.e. per cent are obtained. It will be interesting to note from Fig. 3 that in the majority of cases (12 out of 14) exchangeable sodium has gone down considerably as a result of cane-growing the average loss being about 70 per cent over the control non-cane plots.

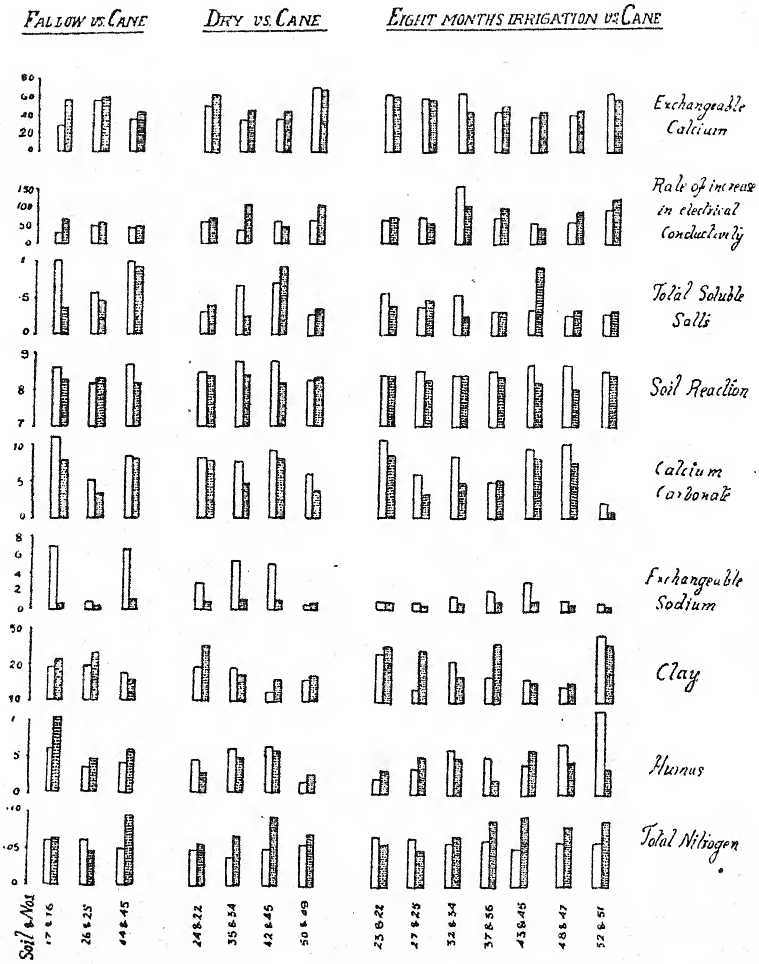

FIG. 3. Effect of irrigation and cane-growing on the physico-chemical properties of soils. N.L.B.C.

Clay and silt. These are determined by the International pipette method [Keen, 1931]. Most of these soils contain round about 20 per cent clay while the silt contents vary widely from 20·6 to 45.0. Increase in clay content has taken place in nine cases there being a fall in the values in five cases due to cane-growing. The average gain in clay during the entire period works out to 1·90 per cent or 34 tons per acre-foot of soil. Similar increases in silt contents of soils are also observed on this canal.

Humus. Determination of this soil constituent has been done according to the method of Sigmond [1927] by extracting the soil with sodium carbonate solution. The values are generally very low in these soils and rarely exceed one per cent. Increases and decreases in humus have taken place in even cases as a result of cane-growing, there being only a slight fall as indicated by the average figure.

Total nitrogen. This has been determined according to the modified method of Bal [1925].

The values range from 0.038 to 0.090 per cent. Generally speaking, nitrogen contents of soils have been increased by cane-growing (10 cases out of 14). The average increase, however, amounts to only 0·016 per cent or about 640 lb. per acre-foot of soil.

Factors responsible for soil deterioration

One of the most important soil properties which control the biological activities in the soils is the carbon/nitrogen ratio of soils. The methods of determination of carbon and nitrogen, and the implications of this ratio on the question of soil fertility have already been discussed in a previous publication [Basu and Vanikar, 1942]. In order to study how these soils, which have been under cane cultivation for a long time, indicate soil deterioration or otherwise when arranged according to the descending order of carbon/nitrogen ratio, 17 cane soils of the Nira Left Bank Canal are graphically represented (Fig. 4) along with other soil properties like nitrogen organic matter, humus and per cent humified matter of these soils. Organic matter (O.M.) was calculated by multiplying organic carbon by 1.724 according to the conventional method [Leather, 1907] and the percentage humified matter obtained by using the formula $\frac{H}{O.M.} \times 100$ where H stands for percentage of humus in soil. The soil deterioration or otherwise is indicated by arrows as usual. It will be noticed from Fig. 4 (A) that soils having carbon : nitrogen ratios higher than 15.0 are all showing signs of deterioration and for values below this, there is a tendency for improvement.

The dotted line shows the nitrogen contents of different soils. Usually, soils having wider ratios show lower nitrogen contents. In Fig. 4(B) the shaded portions represent the humus contents. It will be evident that the deteriorating cane soils show lower humus than the non-deteriorating ones. The total organic matter shows similarly higher average figures for the non-deteriorating when compared with the deteriorating ones. It is also to be noted that the improving soils contain mostly higher percentage of humified matter than the deteriorating soils, the averages being 36.42 and 21.60 per cent respectively.

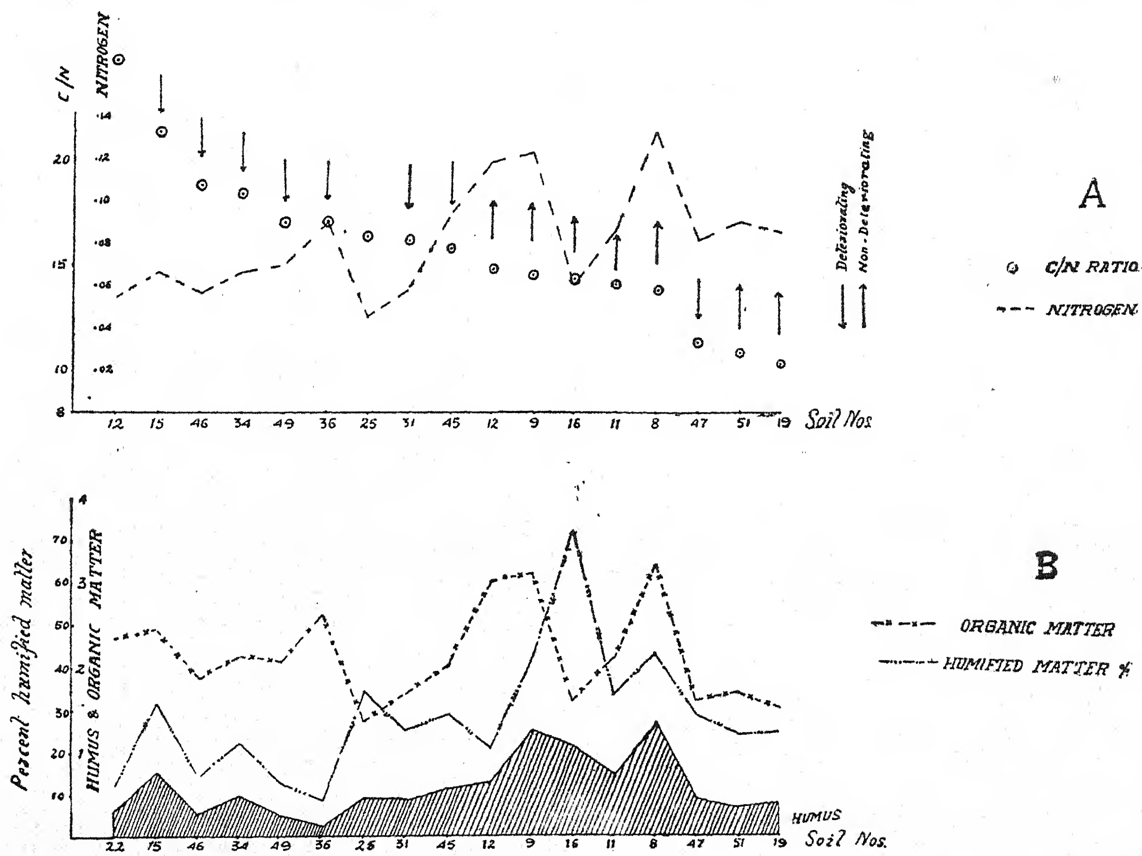

FIG. 4. Soil deterioration as indicated by carbon : nitrogen ratios and other associated soil properties. (N.L.B.C.)

(B) *The Godavari Canals*

Both the Right and Left Bank canals were opened simultaneously in 1911-12, and they soon attracted lot of cultivators especially the cane-growers from the Nira Left Bank canal who were by this time experts in the art of cane-growing. These soils were virgin and undamaged by irrigation, and farmyard manure was available in plenty, and hence these canals flourished, in a very short time, and the cane area rose from 480 acres in 1912 to over 4,000 acres by 1916, and 7,000 acres by 1918. After the last Great War, the prices of *gul* went up very high, and in order to secure very heavy yields, cultivators began to use enormous doses of manure and water. Water-logging and salt efflorescence were the inevitable results. The damaged lands formed 33 per cent of the total area under cane in 1925 and 42 per cent in 1929 [Inglis and Gokahle, 1934]. As a consequence of such wide-spread damage the area under cane began to dwindle down—from an acreage of 9,500 in 1925 it fell to 3,500 by 1931. How the soils behaved under such intensive system of cane cultivation where ratooning is a special feature will be the subject matter of discussion in this section.

Behaviour of cane soils. Twenty-one typical cane soils from the Godavari Right Bank and 29 soils from the Godavari Left Bank were selected for this study. Unlike the Nira Left Bank Canal, these soils had cane only from 4 to 12 years with varying periods of rest (from cane-growing) when dry crops were taken. Hence it afforded us an opportunity of studying soil deterioration under a shorter period of cane-growing. In Fig. 5, the soils are arranged according to descending order of fertility which is calculated from tons of cane produced per 100 lb. nitrogen. Actual tons of cane produced per acre as well as manures in terms of nitrogen are also shown graphically while the soil depth over *murum* are given below the soil numbers. Years under cane and dry crops, are shown by columns against each soil number while the soil deterioration and improvements in the productivity of soils are indicated by arrows. In order to examine these soils

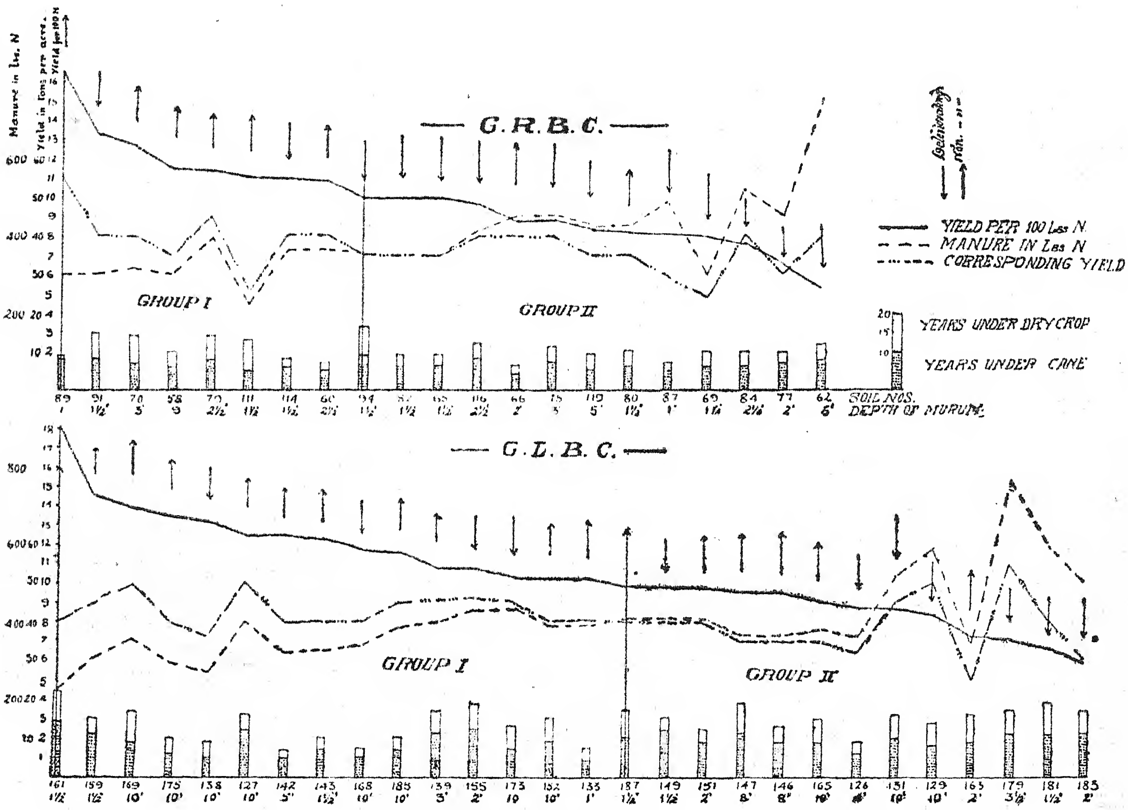

Fig. 5. Fertility status of soils as indicated by cane yields and manuring in terms of nitrogen. (Godavari Canals)

more closely they have been divided into two arbitrary groups—fertile (group I) and less fertile (group II)—by drawing a vertical line at the junction where the curves of actual yield and manure intersect, i.e. soils which produce more than 10 tons of cane per 100 lb. of nitrogen are taken as belonging to the 'fertile' group and others which give 10 or less, as 'less fertile' soils

The most noticeable thing that can be seen from Fig. 5 is that the more fertile soils are deteriorating less than the less fertile soils. Thus on the Godavari Right Bank Canal, we find two out of eight soils in group I deteriorating as against 11 out of 13 in group II. On the Godavari Left Bank Canal there are 4 deteriorating soils out of a total of 15 in group I whereas in group II 8 out of 13 soils are deteriorating. Similar observations were also made in case of the Nira Left Bank Canal. As the exact nature of crop rotations as well as the soils differ considerably on the two canals the discussions on the soil deterioration as affected by crop rotations are given separately below :

On the Godavari Right Bank Canal soils examined were under cane from four to nine years only. It will be apparent from Fig. 5 that soil deterioration is not manifested within four to five years of cane-growing unless the soil is a deep one as in the case of soil No. 119. When we take soils under six years of cane it is noticed that the fertility goes down in most cases where even a four year's rest (from cane-growing) is given, excepting is two cases, i.e. No. 80 and 58, the former being a shallow and the latter a heavy soil. The rotations cane—ratoon—*bajri* and gram—*bajri* adopted for the first and cane—ratoon—*bajri* and gram—*sunn* for the second—seem to be responsible for the maintenance of fertility in the above cases. Cane grown for a period of seven years with rest period up to three years has caused soil deterioration while in soil No. 70 where seven years of rest were given, the fertility has been maintained. With eight years of cane, the same rotation of cane—ratoon—*bajri* and gram—*bajri* seems to be the best (No. 79). Under eight years' cane there is an abnormal case (No. 89) of a shallow soil which has kept up the fertility even under very trying conditions of rotation, namely, cane—3 ratoons—cotton—cane—3 ratoons. But this must be ascribed to the exceptional fertility of the soil—the most fertile of the lot (Fig. 5). There is only one soil with nine years of cane (No. 94) where the rotation cane—ratoon—*bajri*—*bajri* has not been able to retain the productivity of the soil. Evidently, two years of rest from cane-growing are insufficient to maintain the fertility of a shallow soil in the long run where a crop of cane and a ratoon are taken. In the deeper soils ($>$4 ft.) deterioration starts earlier but no generalization can be drawn from the data of this canal as there are only a few deep soils examined here.

On the Godavari Left Bank Canal, shallow soils show deterioration only after 11 to 12 years of cane-growing while in the case of deep soils, deterioration is found to take place even after five to six years of cane. Unfortunately on this canal no fixed rotation has been followed as in the case of the Right Bank. Among the non-deteriorating shallow soils, there is one soil (No. 187) under 10 years of cane with seven years rest from cane, and three soils (Nos. 161, 163 and 151) under nine years of cane with eight, seven and three years' rest respectively, the behaviour of the last-mentioned soil being exceptional as it had in succession three, two and one ratoon with intervening *bajri* crop. Under 11 and 12 years of cane all soils have shown signs of deterioration but the rest-periods from cane-growing are, however, even less than the periods of cane-growing, and hence it is not possible to say whether the fertility of the soils could have been maintained if sufficient periods of rest were provided. Among the 14 deep soils ($>$4 ft.) only five soils have deteriorated under varying years of cane-growing (i.e. between 5 and 8 years). It will be interesting to note in this connection that the incidence of soil deterioration among the deeper soils is much less on this canal when compared with those either on the Godavari Right Bank or Nira Left Bank Canal. The presence of a very well-drained soil on the Godavari Left Bank Canal probably accounts for the abovementioned anomaly. It is a deep black clay loam, 5 to 8 ft. deep, overlying a yellowish white alluvial deposit. Thus while cane—ratoon—*bajri*—*bajri* rotation has not been able to retain the fertility of a deep soil (No. 129) even after eight years of cane-growing the same rotation was found to conserve the soil fertility in the case of soil No. 152 which comes under this well-drained soil type. Instances of such abnormal fertility will be seen in soil Nos. 146, 165, 147 and 127.

Effect of cane-growing on soil properties

A comparative statement showing the number of cases where increase, decrease or no change has taken place in the various soil properties as a result of cane growing and the net average change over the pairs of plots (dry and irrigated) in each canal is given in Table I. Further to test to what extent these results are statistically significant, the data for both the banks, i.e. for 48 pairs of soils under varying years of cane-growing (from 4 to 12 years) are analysed for the important soil properties. For analysis of variance, the total of 95 degrees of freedom is split up into its components as under :

$$\left.\begin{array}{lr}\text{Due to } (i) \text{ irrigation} & 1\\ \quad (ii) \text{ years} & 8\\ \quad (iii) \text{ interaction of } (i) \text{ and } (ii) & 8\\ \quad (iv) \text{ residual error} & 78\end{array}\right\}\text{Total 95 degrees of freedom}$$

TABLE I

Effect of cane-growing on soil properties
(Godavari Canals)

Soil properties	Increase or decrease due to cane-growing							
	Godavari Right Bank Canal—Number of cases				Godavari Left Bank Canal—Number of cases			
	+	—	0	Average	+	—	0	Average
Exchangeable calcium	13	7	0	+1·25 m.e. per cent	13	15	0	+1·27 m.e. per cent
Rate of increase in conductity	12	8	0	+4·38 per cent	20	8	0	+20·14 per cent
Total soluble salts	14	5	1	—0·024 per cent	12	15	1	—0·029 per cent
*p*H in water	6	14	0	—0·032	8	18	2	—0·054
*p*H in N. KCl	7	10	3	—0·024	5	19	4	—0·078
Calcium crabonates	4	16	0	—0·92 per cent	12	16	0	—0·51 per cent
Exchangeable sodium	9	8	3	—0·53 m.e. per cent	6	22	0	—0·38 m.e. per cent
Clay	13	5	0	+4·40 per cent	16	7	2	+2·08 per cent
Silt	8	10	0	—0·96 per cent	9	15	1	—0·82 per cent
Humus	8	12	0	—0·07 per cent	8	20	0	—0·10 per cent
Nitrogen	11	7	2	+0·001 per cent	23	4	1	+0·011 per cent
Available phosphate	9	9	2	+0·001 per cent	21	4	3	+0·003 per cent

TABLE II

Effect of cane-growing on soil properties—Statistical significance of 48 pairs of soils (Dry vs. cane)
(Godavari Canals)

Soil properties / Due to	Observed value of *z*			Expected value of *z* for 1 per cnet point			Significance		
	Irrigation	Years	Interaction	Irrigation	Years	Interaction	Irrigation	Years	Interaction
Exchangeable calcium	—0·9144	0·0303	—0·8998	0·9462	0·4604	0·4604	Not significant	Not significant	Not significant
Rate of increase in conductivity	1·3413	0·5705	—0·0445	0·9462	0·4604	0·4604	Highly significant	Highly significant	Do
Total soluble salts	—0·6703	—0·3608	—0·9824	0·9462	0·4604	0·4604	Not significant	Not significant	Do
*p*H in water	—0·1008	0·4876	0·0500	0·9462	0·4604	0·4604	Do	Significant	Do
Calcium carbonate	—0·2923	—0·0029	—1·1933	0·9462	0·4604	0·4604	Do	Not significant	Do
Humus	—0·5809	—0·7154	—1·2454	0·9462	0·4604	0·4604	Do	Do	Do
Nitrogen	0·8482	0·0222	0·7366	0·9462	0·4604	0·4604	Do*	Do	Significant

* Significant for 5 per cent point in the case of irrigation

A summary of these analyses is given in Table II. These results are briefly discussed below.

Exchangeable calcium. On the Right Bank majority of soils have gained in this property under irrigation and cane-growing, whereas on the Left Bank the cases of gain and loss are almost equal. However, the net result is a gain on both the canals of 1.25 and 1.27 m.e. per cent per plot respectively. On referring to Table II, it will be seen that neither irrigation nor years (of cane-growing) has any statistically significant effect on this soil property. Considering the intimate relationship existing between the nature and amount of soil colloids in the soil profiles and the morphology of different soil types [Basu and Sirur, 1938] it is very likely that the effect of irrigation on this particular soil property may be entirely dependent on the genetic characteristics of these soils.

Rate of increase in electrical conductivity. On both the canals, majority of soils have shown an increase in the property due to irrigation, the Right Bank showing an average increase of 4.38 per cent and the Left Bank of 20.14 per cent per plot. Statistically it will be observed that both the effects of irrigation and years are highly

significant. It seems probable that the rate of increase in electrical conductivity is independent of soil types. It has already been referred to in a previous section that the rate of increase is correlated more closely with the amount of manures applied than with the inherent fertility of different soils.

Total soluble salts. On the Right bank more soils have gained in total salts whereas opposite is true for the Left Bank. Magnitudes of these changes being very small, the net result is nil on the Right Bank and a slight lowering on the Left Bank soils. As the changes due to irrigation are practically very little, there is no statistical significance observed in this property.

Soil reaction. Effect of irrigation is to lower the pH values and exchange acidity in most cases, but there are certain cases where it has raised the values. Net result, however, is a slight lowering of the values on both the banks. On referring to the statistical table it will be seen that the lowering is only significant in the case of 'number of years' which indicates a slow but definite influence of irrigation on soil reaction.

Calcium carbonate. Losses in calcium carbonate under irrigation are general on both the canals, although there are more erratic values on the Left Bank than on the Right. The net result is a loss in both cases, being 0·92 per cent and 0·51 per cent per plot on the Right and Left Bank respectively. Statistically, however, no significance is obtained.

Exchangeable sodium. This soil constituent has been lowered in the majority of cases on the Left Bank while on the Right Bank number of cases is about equal for both gain and loss. The net result is, however, a general lowering of 0.53 m.e. per cent and 0·38 m.e. per cent respectively for the Right and Left Bank Canals.

Clay and silt. In majority of cases, the percentage of clay has increased on both the canals, the average increases being 4·40 and 2.08 per cent on the Right and Left Banks respectively. Slight decreases in the percentage of silt are, however, noted on these canals, significance of which will be discussed later.

Humus. It will be observed that there is a general tendency of lowering of humus by cane-growing but the average figures indicate a very slight loss on the whole. Analyses of variance also do not show any statistical significance either for the effect or irrigation or number of years under irrigation on the humus contents of soils.

Total nitrogen.—It will be observed that cane-growing has generally increased the nitrogen contents of soils in the case of both the canals. Statistical analysis of these data also indicates that the effect of irrigation is significant for $P=0.05$ whereas for interaction between 'irrigation' and 'number of years' the z value is highly significant (i.e. for $P=0.01$).

Available phosphoric acid. On the Godavari Left Bank Canal the majority of cane soils show higher available phosphoric acid by Truog's method [Wright, 1934] than the non-cane soils while on the Right Bank Canal there is an equal number of soils showing increases and decreases due to cane-growing. However, in both cases there are net gains in available phosphoric acid when the averages are taken of all pairs of plots.

Factors responsible for soil deterioration

In Fig. 6 (A and B) cane soils of the Godavari Right and Left Banks have been shown in order of descending C/N ratio, indicating the deteriorating and non-deteriorating soil by means of arrows. Other relevant soil properties like organic matter, humus, per cent humified matter and nitrogen are also indicated by appropriate lines and shading. Most striking thing to note is the fact that above certain limiting C/N ratio (i.e. above 15.0) all soils are showing signs of deterioration in both the canals. It will be remembered that similar observations were also made in connection with the soils of the older canal—i.e. the Nira Left Bank Canal. Coming to the nitrogen curves, it will be seen that unlike the Nira Left Bank Canal soils, the soils with wider C/N ratios show higher nitrogen contents in these canals. Similarly both organic matter and humus contents are higher in the soils with wider ratio which is not the case in the Nira Left Bank Canal. Explanation of this anomalous behaviour will be given later. So far as the per cent humified matter is concerned, the Godavari Left Bank Canal soils are showing higher values for the non-deteriorating than the deteriorating ones, the average figures being 32.91 per cent for the former as against 24.16 per cent for the latter. In the Right Bank, the deteriorating and non-deteriorating soils show equal average values.

(C) *Fertility of sugar-cane soils*

It is already known that the factors responsible for soil fertility differ according to variations in climate, soil and crop. In order therefore to find out the most important soil properties which are primarily responsible for higher productivity of sugarcane soils in the Bombay-Deccan, 31 typical soil samples were collected from the Nira Left Bank and Godavari Canals where reliable history of manuring and cane yields was available. The following precautions were taken in order to get comparable results of soil analysis :

(*a*) All the soil samples were collected in the month of November, within a fortnight, so that the seasonal variation may be negligible.

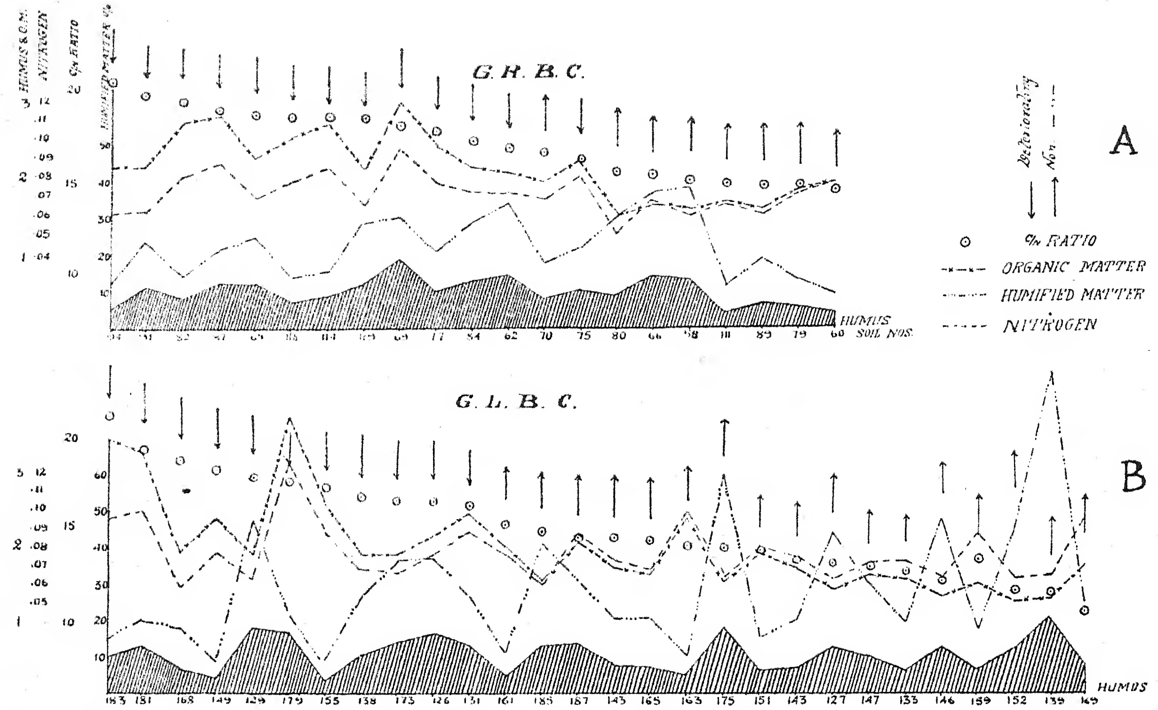

FIG. 6. Soil deterioration as indicated by carbon : nitrogen ratios and associated soil properties. (Godavari Canals)

(*b*) All the plots selected had cane in the previous year, and crops harvested either in January or February (of the year of sampling) so that the periods intervening between the harvesting and sampling were almost the same in all cases.

(*c*) Samples were taken mostly from lands where cotton was standing; in some cases the land was either under *jowar* or *bajri* but in no case leguminous crop was there.

(*d*) Composite sample was made out of 10 individual first foot samples taken at random in each plot and analysed for important soil properties.

For the calculation of soil-fertility status (with reference to cane crop) nitrogen required to produce a 40-ton crop has been taken as an index figure. The soil numbers were arranged in order of descending fertility (i.e. requiring more N to produce a 40-ton crop) and corresponding soil properties entered below each soil number. The first 15 soils were arbitrarily taken to form a 'more fertile group' (Group I) whereas the rest put in a 'less fertile group' (Group II) to study the variations from the mean soil property (mean value for 31 soils) in each of these groups. In order to economize space only these final results are given in Table III.

When contradictory results are not obtained in the two groups, the results are taken to represent the fertility trend of the soils. Results are briefly stated below :

p*H in water*. In general, soils having *p*H values lower than 8·4 are more fertile than those possessing higher values.

p*H in* N *KCl*.—Similarly for *p*H in KCl, values higher than 7·4 indicate lower fertility status.

Calcium carbonate. In the case of calcium carbonate it appears that more fertile soils are associated with lower carbonate contents ($<5·2$ per cent).

Available phosphate. Higher available phosphate (>0.07 per cent) contents indicate better fertility status of soils.

Water-holding capacity. Soils possessing greater moisture-holding capacities (<65 per cent) are usually those which are more fertile.

Nitrogen, nitrate, clay, exchange calcium and rate of increase in electrical conductivity show contradictory results in the two groups and hence no conclusion could be drawn.

In the case of available potash and humus, fertile soils are associated with lower K_2O ($<0·03$ per cent) and lower humus ($<0·8$ per cent) which fact cannot be explained at present.

From the above it will be apparent that although there is no strict relationship between soil fertility and the various soil factors, there is a

TABLE III

Frequency table showing the number of cases occurring above and below the mean values of soil properties in the 'more fertile' (Group I) and 'less fertile' (Group II) soil groups—Nira Left Bank and Godavari Canals

Soil properties	Mean value for 31 soils	Group I (More fertile soils) No. of cases out of 15 soils		Group II (Less fertile soils) No. of cases out of 16 soils	
		Values above the mean	Values below the mean	Values above the mean	Values below the mean
pH in water	8·39	5	10	9	7
pH in N. KCl	7·37	6	9	10	6
Calcium carbonte	5·19 per cent	6	9	8	8
Nitrogen	0·083 per cent	6	9	7	9
Available phosphate	0·069 per cent	10	5	7	9
Available potash	0·030 per cent	5	10	10	6
Nitrate	0·296 mg. per 100 gm. soil	7	8	4	12
Humus	0·83 per cent	6	9	10	6
Clay	53·23 per cent	7	8	7	9
Maximum water holding capacity	64·71 per cent	8	7	6	10
Exchangeable calcium	56·16 m.e. per cent	8	7	10	6
Rate of increase in electrical conductivity	124·49 per cent	8	7	10	6

general trend in the case of at least five soil properties. Generally speaking the more fertile soils are characterized by lower pH values (both in water and N KCl) and lower calcium carbonate but higher available phosphate and higher water-holding power. Want of a closer relationship may be due to the fact that the variations in soil types may be responsible for the changes in the limiting values in soil properties beyond which the yields of cane crop are affected.

GENERAL DISCUSSION AND CONCLUSIONS

The question of the effect of crop-growing on soil fertility has attracted the attention of various workers. There are two aspects of this question to be considered: firstly there is the immediate effect or growing a crop on the succeeding crop, and secondly the ultimate effect on the soil as a result of long-continued crop-growing either singly or in rotation with other crops. In a previous paper [Basu and Sirur, 1943] the effect of various rotational and green manuring crops on the succeeding cane crop has been fully discussed with special reference to soil tilth and other fertility factors. In the present paper data have been presented on the long-continued effects of cane-growing on soil fertility as revealed by a survey of sugarcane soils of three major canals of the Bombay-Deccan. The present position of this work is briefly reviewed here.

General trend in soil fertility due to cane-growing

It has been pointed out in a previous communication [Basu, 1942] that although there is no single absolute method of assessig soil fertility it is nevertheless possible by adopting several methods at the same time to approach to a fair understanding of the fertility status of a soil. To determine the fertility changes due to cane-cropping the straight-forward means of analyzing soils from pairs of adjacent plots—one having cane for long time and the other where no cane was ever taken—had to be resorted to. The results of these soil changes are discussed under three broad heads: (*i*) Physical, (*ii*) Plant nutrients, and (*iii*) Biological status.

Among the physical properties studied, taking first the changes in the mechanical composition of soils it is interesting to observe that the percentage of clay has increased due to cane-growing on all the canals. Two explanations can be offered: (*a*) mechanical breakdown of the coarsel particles as a result of intensive agriculturar operations associated with cane-growing, and (*b*) addition of finer suspended materials from the irrigation water specially during the monsoon months. The decrease in silt on the Godavari Canals, however, can partly be accounted for by assuming mechanical breakdown of silt particles whereas in the case of the older canal (Nira Left Bank) where both clay and silt have increased it may be taken that this process of disintegration has extended to coarse and fine sand fractions as well.

Exchangeable bases (i.e. calcium and sodium which have been determined in this survey) show interesting relationship in all the canals. There has been a general increase in calcium colloid

while a fall is noticed in sodium colloid (though not in equal amounts) as a result of cane-growing. As can be expected the older canal has shown greater changes when compared with comparatively newer canals. That the increase in exchangeable calcium at the expense of the other bases including sodium, is a natural pedogenic process in these calcareous soils when brough under irrigation with proper drainage, has been dealt with at length previously [Basu and Tagare, 1943], and need not be discussed here further. This improvement in soil colloids is reflected in slight lowering in pH values in all cases. As in this survey we have avoided atcually waterlogged and salt-affected soils the lowering in soluble salts has been, in general, rather small.

As regards nutrient status, available soil data indicate that cane-growing has not exhausted the soil so far as total nitrogen and available phosphoric acid are concerned. On the other hand, in the majority of cases there has been increase in nitrogen, the results of the Godavari Canals showing statistical significance. This is not surprising when we consider the manuring doses. Normally a cultivator's dose of nitrogen in the manures applied comes to 400 lb. per acre, out of which 250 lb. N is given as top-dressing (200 lb. N as cake plus 50 lb. N as sulphate of ammonia) while the rest supplied by farmyard manure, the latter being, however, hardly available to the cane crop. Taking the data worked out by the Physiological Section of the Station, a 42-ton crop of POJ 2878 obtained on a top-dressing of 225 lb. N (in the case of Pundia it is slightly less) can remove 152 lb. N, 48 lb. P_2O_5, 300 lb. K_2O and 151 lb. CaO from the soil. The average yield of cane being round-about 40 tons on these canals we find that a little more than half of the nitrogen supplied by the cake and sulphate is utilized by cane while the rest is generally lost by leaching. Of the 150 lb. N supplied by farmyard manure 40 per cent remains in the soil according to our data of controlled experiments in the farm. The above manuring supplies in addition 211 lb. P_2O_5 and 181 lb. K_2O. Thus taking into consideration even the leaching down of P_2O_5 by irrigation water (which is about 40 lb. P_2O_5 annually) there remains a surplus of P_2O_5 in the soil. Potash reserve of soil is, however, tapped by cane-growing but as most of the Deccan soils are well supplied by potash this aspect has not received our attention in this paper. Lastly, coming to the consideration of losses of lime (carbonate) from soils we find a very heavy drain (about 4,000 lb. per acre per annum) from all canals although the quantity removed by crops is small. This is expected as the percolating water in cane fields is usually highly charged with carbonic acid due to intense root and bacterial activities.

Increase in the rate of electrical conductivity in all the canals as a result of cane-growing indicates that the biological conditions of these soils have been improved. On the Godavari canals, where statistical examination of data has been possible, it is observed that with increasing number of years of cane-growing this effect is more and more pronounced (i.e. highly significant for irrigation and years). Qualitatively it is also observed that this increase is correlated more with the amount of manures applied than with the inherent fertility of the soils. Thus it appears that cane soils develop a greater microbial activity due to the nature of manuring practised, which consists mostly of bulky organic matter. Respiration studies conducted on soils from controlled experimental plots at the farm also show that cane-growing increases the microbiological activities of soils even when no manure is applied, but more so, when manured. This increased microbial activity is naturally expected to be linked up with increased carbon (energy material) in cane soils but unfortunately this comparative data for cane and non-cane plots are not available for all canals. In the case of the older canal—Nira—where it has been determined, considerable increase in carbon is actually observed. Humus (i.e. dilute alkali-soluble fraction) on the other hand shows losses in all canals, and this in all probability, can be explained as due to excessive irrigation as practised by the cultivators, which induces mobilization of humus in an alkaline medium obtaining in the highly calcareous soils of the Deccan canals.

Deterioration in cane soils and its causes

So far we have discussed the general trend in soil fertility as a result of cane-growing. Now we shall examine what specific changes are observed when soils begin to show signs of deterioration, which is reflected in gradual lowering in yields of cane per unit nitrogen. Among the various soil factors examined in this connection consistent results have been obtained in the case of carbon/nitrogen ratio, which shows definite widening (usually greater than 15·0) in the case of deteriorating cane soils. Regarding the actual nitrogen or carbon contents of these soils no generalization can, however, be drawn as contrary results are obtained in case of the Nira and Godavari Canals. When we examine the average nitrogen doses applied in the past for the deteriorating and non-deteriorating soils of these canals the apparent anomaly becomes explicable. These figures together with the average data of soil analysis are given in Table IV.

It will be seen that in the case of Nira Canal non-deteriorationg soils have received greater nitrogen than the deteriorating ones, while reverse is

TABLE IV

Average data for nitrogen applied to deteriorating and non-deteriorating soils, and the nitrogen, carbon and humus contents of these soils—Nira Left Bank and Godavari Canals

		Average manure applied in terms of lb. of N	Nitrogen content of soil per cent	Organic carbon per cent	Humus per cent	Percentage Humified matter
Nira Left Bank Canal	D	345	0·073	1·233	0·42	21·60
	N-D	402	0·099	1·341	0·82	36·42
Godavari Right Bank Canal	D	428	0·076	1·438	0·55	22·31
	N-D	349	0·067	1·036	0·39	22·16
Godavari Left Bank Canal	D	474	0·082	1·467	0·57	24·16
	N-D	354	0·073	0·959	0·51	32·91

the case of both the canals of Godavari. This residual effect of higher manuring on the nitrogen and carbon contents is also reflected to a certain extent on the humus contents of these soils. The percentage humified matter on the other hand shows a characteristic lowering (with soil deterioration) in both the Nira and Godavari Left Bank, while in case of the Godavari Right Bank, in spite of higher humus contents of the deteriorating soils, the humified matter remains more or less constant. This fact indirectly shows that in the deteriorating soils losses suffered by the humified fraction of the total organic matter are greater probably due to injudicious irrigation resulting in greater leaching down of soluble organic constituents of the soil.

It has been shown previously [Basu and Vanikar, 1942] that the application of heavy dose of farmyard manure may lead to increased carbon/nitrogen ratio when the moisture saturation is kept at a high level. Under such a condition the algal growth in the soil is generally vigorous which has been shown to be associated with the ultimate increase in soil carbon. Increased moisture saturation in these cane fields may result from either over-irrigation or ill-drained condition of the soil or from both these factors. From our results of this survey it appears that the adoption of a suitable crop rotation (probably due to occasional cultivation and partial drying out of the soil) can counteract to a great extent this progressive increase in the carbon/nitrogen ratio of these soils and thus avert this calamity of falling cane yields.

On the Nira Left Bank Canal, where cane has been grown for a long time, it has been observed that in a very well-drained shallow soil ($<$2 ft. deep) even a two-year rotation of cane (one year cane with one year another crop) has been able to maintain the fertility of the soil while in a deeper soil ($>$ 4 ft. deep) a four-year ratation (one cane in four years) seems to be essential. From the Godavari Canal survey, it appears that a ratoon is far more exhausting than a plant cane crop. Thus two years of rest from cane-growing are found to be insufficient to maintain the fertility of a shallow soil where a crop of plant cane and a ratoon are taken. Although in a deeper soil for the same rotation a much longer rotation is expected for the maintenance of fertility, it is interesting to note that much depends on the actual drainage condition of such a soil, which is ultimately governed by the nature of 'B' horizon in a soil profile [Basu and Tagare, 1943]. For instance in an exceptionally well-drainaged deep soil type of the Godavari Left Bank (where the 'B' horizon consists of yellowish while alluival sands) it is found that even a four-year rotation with cane—ratoon and two other crops—retained the fertility intact. Similar instrances are not wanting even in the case of shallower soils where very trying rotations have proved successful. Thus in recommending the rotation of a soil for sugarcane cultivation it will be worthwhile to have a general survey of soils made for the types, in order to avert any disaster due to indiscriminate use of lands under perennial irrigation, without a sound policy of crop rotation based on scientific studies of the soil.

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STUDIES ON BUNDELKHAND SOILS

I. THE GENETIC TYPES

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GENERAL

THE part of the United Provinces lying south-west of the river Jumna is known as Bundelkhand. The soils of this tract are entirely different from those of the province as a whole, since the tract differs geologically from the rest in being non-alluvial in nature. The district of Jhansi from where the soils reported in this paper were collected lies in the extreme south-west corner of the tract between the parallels of 28°11′ and 25°51′ north latitude and 78°10′ and 79°25′ east longitude. This part is a most representative tract of the whole region due to its peculiar topography, and the various soil types occurring in the whole of Bundelkhand can easily be found in this district.

The general landscape of the Bundelkhand tract is that of a bare undulating plain with irregular rocky hills converging to a level expanse of black soil towards the north reaching up to the river Jumna. On the extreme south and south-west lie the Vindhya ranges. The general slope of the country is from north to south and as one passes through the level plains on the south of the Jumna to the rocky hills, the fertile black soil converges into coarse-grained red soil interspersed with brownish to black patches.

Geologically the whole of the Bundelkhand tract is occupied by gneiss. The formation consists of massive granite rocks traversed by gigantic quartz reefs forming the hill ranges. At times sandstones, limestones and slates are also to be met with. Some of the beds are highly ferruginous and iron has become localized at the surface 'probably due to lateritic action'. The only other geological formation found in the tract is the cretaceous sandstones of the Lameta group [Drake-Brokeman, 1909].

(*i*) *Soils*

The soils can be classified into two broad divisions, viz. (*a*) black soils and (*b*) red soils. The black soils are usually very adhesive when wet and expand and contract to a remarkable degree, thus becoming fissured in the hot season. These are locally known as *mar* and *kabar*. *Mar* is usually less clayey than *kabar*, but both these types are highly retentive of moisture and could be cultivated without much irrigation. These are the typical analogues of the so-called black cotton soils of Central India popularly known as the *regur* soils.

Amongst the red soils there are two types locally known as *parwa* and *rakar*. *Parwa* is a brownish grey soil varying from a good loam to sandy or clayey in texture and is a fairly good soil which responds easily to manure and irrigation. *Rakar* is the true red soil which is generally worthless for cultivation. It is the eroded soil of the tract and is thus usually found on higher elevations. In general the red soils are found more towards the south of the tract where it adjoins the Central Indian hills.

(*ii*) *Vegetation and agriculture*

The natural vegetation of the tract consists of grasses and shrubs. Trees are usually absent, but at times *ber* (*Ziziphus rotundifolia*) and *dhak* (*Butea frondosa*) grow on better types of land. Spear grass is the most common grass of the locality although better varieties like *anjan* (*Pennisetum cenchroides*) may be found in low-lying areas. In places having *kabar* and *mar* soils *kans* (*Saccharum spontaneum*) grows wild and its eradication is a serious problem.

The general agriculture of the tract is of a very low order. The poor nature of the soil and scarcity of water are the two chief factors responsible for this condition. The black soil areas are mostly cultivated; whereas the less fertile red soils are cultivated only if irrigation facilities are available. Most of the cultivation is done during the *kharif* and little is possible during the *rabi* except on good black soil. *Jowar*, smaller millets and *til* are the principal *kharif* crops, and wheat, gram and linseed the principal *rabi* crops. Wheat and *jowar* are generally put on better soils and gram and smaller millet occupy soils of lesser fertility.

(*iii*) *Climate*

The climate of Bundelkhand, as might be expected from the rocky nature of the tract, the rapid drainage, the absence of jungle and the depth of water-level, is characterized by exceeding dryness and heat considerably above the average of the province. May and June are intensely hot and the rainy season is also at times marked

by unusually high temperatures. In the cold weather the air is dry and chilly although frosts are usually absent. The mean annual temperature is 79·0°F. and the mean annual rainfall 36·4 in. The coldest month is January with an average of 62°F. and hottest is May or June with 94·5°F. The maximum temperature in hot weather is at times recorded as high as 116°-120°F.

The usual meteorological data for Jhansi proper are given in Table I.

TABLE I

Average monthly meteorological data for Jhansi

Month	Temperature			Rainfall		
	Max. (°F.)	Min. (°F.)	Mean (°F.)	Total rainfall (in.)	No. of rainy days	Relative humidity (per cent)
January	76·4	37·3	62·0	0·56	1·2	54·3
February	81·4	41·4	68·0	0·40	0·8	45·6
March	93·1	49·4	78·0	0·23	0·5	36·9
April	104·2	60·9	88·0	0·14	0·5	30·2
May	108·3	68·1	94·5	0·24	0·7	31·0
June	102·8	71·3	92·8	4·43	5·8	48·5
July	91·2	71·9	83·9	11·81	13·1	77·8
August	88·9	71·0	82·6	11·50	12·7	80·5
September	91·7	68·4	82·2	6·08	6·8	74·2
October	92·9	50·0	79·9	0·63	0·9	53·6
November	85·3	42·3	71·8	0·07	0·1	45·2
December	78·4	40·7	63·9	0·28	0·8	51·0
Mean	91·2	39·1	79·0	36·37	43·9	52·3

Note —Monthly mean temperatures are the averages of 16-18 years, whereas rainfall figures are the average of 47 years

It will be seen that the rainy season lasts from the middle of June to the middle of September and that during this period practically the whole annual precipitation takes place. It may be mentioned that rains usually come in heavy downpours and thus bring about considerable erosion. During the rainy season one finds alternately hot and wet periods which are responsible for considerable weathering of the soil and leaching away of the weathered products. Winter rains are practically absent. Lang's [1915] rain factor for the locality is 34·9 mm. per degree centigrade and Meyer's [1926] N.S. quotient is 78·8, showing that the climate may be characterized as semi-arid.

(iv) Literature

Literature on the black and red soils of India is extremely meagre. Sahasrabudhe [1929] in his note on soils of the Bombay Presidency compiled only the available scattered data on those soils. Basu and Sirur [1938] are the pioneer workers who scientifically surveyed the soils of the Deccan canal area and classified them on modern pedological principles. Their work is unique, for it throws considerable light on the chief pedogenic processes responsible for the different types of *regur* soil found in the Bombay-Deccan.

(v) Technique employed

A number of pits were dug at the Government Cattle Farm, Bharari, Jhansi, at sites which were considered representative of the different soil types of the tract. The samples of soil were collected horizon-wise. Observations in regard to the visual characteristics of each horizon were recorded *in situ*, particularly with regard to colour, texture, structure, depth and hardness. A number of such profiles from each type were examined and results of the selected ones have been presented in the body of the paper.

The usual laboratory methods for the analysis of the hydrochloric acid extract on 2 mm. samples of soil were followed. *p*H was determined colorimetrically, total exchangeable bases by the method of Williams [1929] and exchangeable calcium by Hissink's sodium chloride method [1923]. Mechanical analysis was done by the International pipette method after pre-treatment with hydrogen peroxide and dispersion by sodium hydroxide. The separated clay fraction was analysed after fusion with sodium carbonate according to the method of Robinson as described by Wright [1939].

EXPERIMENTAL

From the results of the visual observations on the profile and the analytical data obtained it

seems obvious that the soils of the district of Jhansi in particular and of the Bundelkhand tract in general contain amongst other soil types three distinct genetic types depending upon the developmental characteristics of the profiles. These three types have been mentioned in the text of the paper as Types I, II and III. Morphological, chemical, mechanical and physico-chemical data of the three types have been presented under each head. It will be observed that differences in the types are mainly due to differences in topographical conditions and subsequent differences in weathering and leaching. The data for the three types are presented separately to enable a comparison being made among them.

Type I

Morphological. The pit was situated at a higher level than the surroundings. The soil was very coarse and compact, having a reddish brown colour. The sample was obtained from an uncultivated portion for profile No. 1 and from near a recently cultivated portion for profile No. 2 which was also at a slightly lower level as compared to the site at which pit No. 1 was dug.

TABLE II

Visual characters

Horizon	Depth	Sample depth	Description
		Profile No. 1	
I	0 in.—7 in.	0 in.—7 in.	Brown soil with loose sandy texture more or less crumby structure, presence of some roots, no colour with phenolphthalein ; no reaction with HCl
II	7 in.—5 ft. 5 in.	7 in.—2 ft. 5 in. 2 ft. 5 in.—3 ft. 11 in. 3 ft. 11 in.—5 ft. 5 in.	Red hard compact soil ; coarse grained ; impregnated with red particles of iron oxide ; no colour with phenolphthalein ; no reaction with HCl
III	5 ft. 5 in.—6 ft.	5 ft. 5 in.—6 ft.	Parent material ; hard and rock like big stones
		Profile No. 2	
I	0 in.—5 in.	0 in.—5 in.	Reddish yellow coarse grained soil loosely packed ; sparse growth of roots ; no colour with phenolphthalein ; no reaction with HCl
II	5 in.—3 ft. 2 in.	5 in.—1 ft. 9 in. 1 ft. 9 in.—3 ft. 2 in.	Dark brown soil ; loosely packed with *murrum* with big-sized stones towards the bottom ; no reaction with phenolphthalein ; no reaction with HCl
III	3 ft. 2 in.—4 ft.	3 ft. 2 in.—4 ft.	Big-sized stones loosely held

A consideration of the morphological data indicates that the soil is a coarse-grained material and that good soil lies on the top as a superficial cover up to a depth of a few inches only. The horizons are very clear-cut and the weathered parent rock can be met with only within 4 to 5 ft. of the soil. Topographically such soils are found at elevated spots and at the foot of hilly portions of the area. In general appearance these soils look like eroded soils.

In Table III are presented the data for the composition of the hydrochloric acid extract of the soil material.

Moisture and loss-on-ignition figures are more or less uniform throughout the profile with a tendency to be low at the surface layer due probably to its lower clay content. The first horizon is highest in insoluble residue and it decreases in the next only to increase again in the last horizon. Soluble silica in profile No. 2 is low in the top horizon. This indicates that the products of the disruption of the silicate complex have been washed down the profile and this fact is further corroborated by a study of the distribution of sesquioxides. Both iron and alumina are low in the top horizon and increase to more or less a constant level in the next layers. Leaching is further indicated by a gradual washing of both lime and magnesia to lower depths. Profile No. 1 is markedly low in potash, but the other profile is not so poor. Water-soluble salts are very low. The mechanical analysis data are tabulated in Table IV.

Table III

Analysis of the hydrochloric acid extract

(Per cent air dry basis)

Profile No. 1

Particulars	0 in.—7 in.	7 in.—2 ft. 5 in.	2ft. 5 in.—3 ft. 11 in.	3 ft. 11 in.—5 ft. 5 in.	5 ft. 5 in.—6 ft.
Moisture	0·61	2·75	2·60	0·68	1·47
Loss on ignition	2·20	5·95	5·17	5·62	3·47
Total insolubles	91·46	74·20	76·66	76·02	81·49
Sesquioxides	4·74	14·08	13·42	12·62	10·63
(a) Fe_2O_3	1·90	4·45	4·09	4·61	3·95
(b) Al_2O_3	2·85	9·53	9·25	7·93	6·60
CaO	0·49	0·97	0·73	0·84	0·75
MgO	0·58	0·82	1·01	1·66	1·32
K_2O	traces	traces	traces	traces	traces
P_2O_5	0·09	0·10	0·08	0·08	0·08
Total water solubles	0·09	0·04	0·08	0·09	0·10

Profile No. 2

Particulars	0 in.—5 in.	5 in.—1 ft. 9 in.	1 ft. 9 in.—3 ft. 2 in.	3 ft. 2 in.—4 ft.
Moisture	2·62	3·75	2·72	2·04
Loss on ignition	3·67	4·93	3·49	3·93
Total insolubles	72·81	62·40	67·76	76·26
(a) Soluble SiO_2	15·96	23·60	20·37	20·43
Sesquioxides	17·18	25·49	19·38	21·43
(a) Fe_2O_3	5·84	8·56	6·84	9·36
(b) Al_2O_3	11·30	16·86	12·44	11·94
CaO	0·69	1·02	2·02	2·41
MgO	0·81	1·99	2·09	1·09
K_2O	1·13	1·04	0·64	1·98
P_2O_5	0·05	0·07	0·10	0·13
Total water solubles	0·06	0·06	0·08	0·08
$\frac{SiO_2}{R_2O_3}$ (mol)	1·86	1·85	2·25	2·12
$\frac{SiO_2}{Al_2O_3}$ (mol)	2·66	2·48	3·06	3·10
$\frac{Al_2O_3}{Fe_2O_3}$ (mol)	2·92	2·97	2·75	1·93

Table IV

Mechanical analysis (2 mm. sample)

(Per cent air dry basis)

Profile No. 1

Particulars	0 in.—7 in.	7 in.—2 ft. 5 in.	2 ft. 5 in.—3 ft. 11 in.	3 ft. 11 in.—5 ft. 5 in.	5 ft. 5 in.—6 ft.
Coarse sand	43·37	24·85	32·30	42·23	53·85
Fine sand	40·38	22·83	26·36	20·16	23·81
Silt	15·10	21·25	17·10	18·60	22·42
Clay	5·05	18·00	13·05	10·15	3·75

Profile No. 2

Particulars	0 in.—5 in.	5 in.—1 ft. 9 in.	1 ft. 9 in.—3 ft. 2 in.	3 ft. 2 in.—4 ft.
Coarse sand	21·10	22·35	50·32	44·46
Fine sand	29·75	24·29	21·60	20·89
Silt	15·45	16·05	11·10	11·30
Clay	31·25	36·75	13·60	19·65

The highly coarse nature of the soil is indicated by a very high coarse sand content throughout the whole profile. Clay and silt together constitute only about 25-30 per cent of the whole soil except in the two top layers of profile No. 2 which had received eroded washings from the neighbouring plots as a result of artificial embankment at a distance of nearly a furlong or so. There is a slight eluviation of clay from the top horizon which makes the lower horizons more compact. In general, the soils appear to have been subjected to high erosion whereby the finer materials have been washed away. Soils represented by profile No. 2 are, however, texturally better than those represented by the other profile. It seems that much improvement in the physical condition of soils of this type can be brought about by simply checking erosion. The data for the physico-chemical analysis are presented in Table V.

TABLE V

Physico-chemical analysis

Profile No. 1

Particulars	0 in.—7 in.	7 in.—2 ft. 5 in.	2 ft. 5 in.—3 ft. 11 in.	3 ft. 11 in.—5 ft. 5 in.	5 ft. 5 in.—6 ft.
Moisture (natural) per cent	2·44	6·69	9·03	6·12	3·60
Moisture equivalent per cent	12·23	25·92	27·97	15·18	17·70
Water-holding capacity per cent	32·75	57·10	33·06	53·48	42·44
pH in N-KCl	6·0	6·0	6·0	7·2	7·2
Total nitrogen per cent	0·057	0·066	0·049	0·031	0·029
Total carbon per cent	0·47	0·35	0·82	0·35	0·47
C/N ratio	8·25	5·30	16·7	11·3	16·2
Total exchangeable bases m.e. per cent	5·0	15·0	14·48	16·18	14·00
Total exchangeable calcium m.e. per cent	5·0	14·32	14·0	15·12	13·24
Per cent Ca of the total bases	100·0	95·4	96·5	93·5	94·5

Profile No. 2

Particulars	0 in.—5 in.	5 in.—1 ft. 9 in.	1 ft. 9 in.—3 ft. 2 in.	3 ft. 2 in.—4 ft.
Moisture (natural) per cent	1·38	13·37	11·89	13·94
Moisture equivalent per cent	27·3	29·0	20·8	24·7
Water-holding capacity per cent	44·04	49·09	35·80	40·03
pH in N-KCl	6·5	6·9	7·3	7·5
Total nitrogen per cent	0·021	0·049	0·034	0·006
Total carbon per cent	0·79	0·57	0·21	0·25
C/N ratio	37·3	11·6	6·2	41·6
Total exchangeable bases m.e. per cent	18·40	27·36	29·44	26·74
Total exchangeable calcium m.e. per cent	18·32	24·00	19·52	19·68
Per cent Ca of the total bases	99·5	81·5	66·3	73·8

It is evident from Table V that pH increases with depth and that the top horizons are slightly acidic (6·0—6·5). This indicates acid leaching of the entire profile. The nitrogen content is poor (0·02—0·05 per cent) and the poor top layer lies on a subsoil comparatively richer in nitrogen. Afterwards nitrogen decreases to a very low figure. C : N ratios are erratic. The organic matter content and base status of the profile is low, specially so in profile No. 1, but the exchange complex is more or less fully saturated with calcium—a fact which gives a fairly good crumb structure to the top soil. Although the absence of a zone of calcium carbonate accumulation has given these profiles an acidic character, it is significant to note that the degradation has not proceeded to the extent so as to make the exchange complex low in calcium.

The separated clay fraction was analysed for its chief ultimate constituents in the case of profile No. 2. The results of this analysis are presented in Table VI.

It seems that there is a slight eluviation of silica from the top horizon. Alumina also seems to be leached down but iron accumulates in the top layers. $SiO_2 : R_2O_3$ ratio increases with depth showing greater leaching of silica as compared to sesquioxides. Similar results are obtained if the ratios are calculated in the bulk sample of the soil (Table III). $SiO_2 : Al_2O_3$ ratio in the clay fraction and in the soil also shows a greater mobility of silica as compared to alumina In the clay fraction, however, the $Al_2O_3 : Fe_2O_3$ ratio increases with depth as a result of accumulation of iron in the top layers This may be responsible for the characteristic red colour of the top soil.

Type II

Morphological. The pit was situated at a comparatively lower level than the areas at which pits representing Type I were dug. The soil was brownish red in colour and looked better in texture. The samples were obtained from a recently cleared jungle area.

TABLE VI

Ultimate analysis of clay

Profile No. 2

Horizons	SiO_2 per cent	R_2O_3 Per cent	Fe_2O_3 per cent	Al_2O_3 per cent	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
0 in.—5 in.	35·74	31·77	13·46	18·31	2·25	3·32	2·13
5 in.—1 ft. 9 in.	37·89	34·40	14·53	19·87	2·21	3·24	2·15
1 ft. 9 in.—3 ft. 2 in.	37·63	31·15	12·40	18·75	2·41	3·41	2·37
3 ft. 2 in.—4 ft.	42·15	32·18	12·36	19·82	2·59	3·62	2·52

TABLE VII

Visual characters

Profile No. 3

Horizon	Depth	Sample depth	Description
I	0 in.—10 in. . .	0 in.—10 in. . .	Loose, yellowish grey soil; single grained; no reaction with HCl
II	10 in.—3 ft. 9 in. .	10 in.—2 ft. 3½ in. . 2 ft. 3½ in.—3 ft. 9 in.	Hard and compact; reddish brown soil with big roots; no reaction with HCl
III	3 ft. 9 in.—6 ft. .	3 ft. 9 in.—4 ft. 10½ in. 4 ft. 10½ in.—6 ft.	Hard soil with *kankar*; reddish grey colour; looks more clayey; vigorous reaction with HCl

As compared to Type I this profile shows greater depth and the most important feature is the presence of a zone of calcium carbonate accumulation in the form of *kankar* layer at the bottom. The colour of the soil is also brownish as compared to Type I which is redder in shade.

Considering the results of the analysis of hydrochloric acid extract presented in Table VIII it is evident that moisture and loss-on-ignition figures are lower in the top horizon than those for the bottom layers, indicating a slight eluviation of colloidal matter. Insoluble residue decreases with depth although soluble silica is more in the second and third layers. There is a slight leaching of the sesquioxides from the first layer and they accumulate uniformly in other layers, iron being more affected than alumina; although in the case of the latter ingredient there seems to be a gradual accumulation with depth. Lime has been washed down and accumulates in lower horizons, whereas, magnesia does not seem to be so affected. Water-soluble salts are more or less uniform throughout the profile.

As compared to Type I, these figures show that although there has been a translocation of the weathering products of silicate complex to lower depths, these are not so pronounced as in Type I. The presence of calcium carbonate layer at the bottom has probably given greater stability to this complex. This is a typical feature of calcium soils. The results of the mechanical analysis of the profile are given in Table IX.

TABLE VIII

Analysis of hydrochloric acid extract

(Per cent air-dry basis)

Profile No. 3

Particulars	0 in.—10 in.	10 in.—2 ft. 3½ in.	2 ft. 3½ in.—3 ft. 9 in.	3ft. 9in.—4 ft. 10½ in.	4 ft. 10½ in.—6 ft.
Moisture	0·70	1·37	1·73	1·48	1·28
Loss on ignition	1·45	2·25	2·04	0·92	1·00
Totoal insolubles	88·13	82·97	80·81	77·61	64·72
SiO_2	10·33	12·59	13·98	11·56	12·89
Sesquioxides	7·47	10·52	12·70	13·28	12·79
Fe_2O_3	2·76	4·64	4·80	4·18	4·34
Al_2O_3	4·65	5·76	7·77	8·98	8·35
CaO	0·56	0·67	0·83	6·71	10·44
MgO	0·16	0·47	0·10	0·10	0·05
K_2O	0·08	0·19	0·16	1·62	0·58
P_2O_5	0·07	0·12	0·13	0·12	0·10
Total water solubles	0·11	0·08	0·08	0·17	0·10
SiO_2/Al_2O_3	3·77	3·56	3·06	2·19	2·62

TABLE IX

Mechanical analysis (2 mm. sample)

(Per cent air-dry basis)

Profile No. 3

Particulars	0 in.—10 in.	10 in.—2 ft. 3½ in.	2 ft. 3½ in.—3 ft. 9 in.	3 ft. 9 in.—4 ft. 10½ in.	4 ft. 10½ in.—6 ft.
Coarse sand	8·29	4·54	2·21	1·67	1·07
Fine sand	60·05	53·91	50·39	39·32	36·88
Silt	10·80	14·50	16·10	14·92	19·05
Clay	14·55	25·45	28·25	25·43	20·25

With the exception of the first layer, silt and clay together constitute nearly 40 per cent of the soil. The texture of this type is, therefore, loamy and unlike that of Type I is more desirable for cultivation. Coarse sand fraction is low, whereas fine sand fraction is over 50 per cent in the three top layers. There is a slight eluviation of clay from the first to the second layer.

TABLE X

Physico-chemical analysis

Profile No. 3

Particulars	0 in.—10 in.	10 in.—2 ft. 3½ in.	2 ft. 3½ in.—3 ft. 9 in.	3 ft. 9 in.—4 ft. 10½ in.	4 ft. 10½ in.—6 ft.
Moisture (natural) per cent	7·24	10·59	8·93	2·98	9·56
Moisture equivalent per cent	20·90	28·30	30·80	25·50	23·50
Water holding capacity per cent	40·00	48·30	48·30	47·60	46·00
*p*H in *N*-KCl	7·4	6·4	6·9	7·1	7·3
Total nitrogen per cent	0·060	0·056	0·053	0·039	0·032
Total carbon per cent	0·39	0·31	0·15	0·17	0·13
C/N ratio	6·5	5·5	2·8	4·3	4·1
Total exchangeable bases m.e. per cent	11·68	14·72	17·04	18·80	13·0
Total exchangeable calcium m.e. per cent	9·6	14·13	16·70	16·16	12·8
Per cent Ca of the total exchangeable bases	82·0	96·0	98·0	86·0	98·5

A study of the data presented in Table X shows that with the exception of the second layer the *p*H of the profile is within the neutral range. Total nitrogen content and the organic matter content are highest at the top and decrease downwards. The base-exchange status is more or less similar to that of Type I and the exchange complex is mainly saturated with calcium, thus giving proper tilth to the soil.

The results of the clay analysis (Table XI) point clearly to some of the striking differences between the soils belonging to Type I and those belonging to Type II. In Type I it was observed that there is a slight migration of both silica and alumina from top to bottom layers, but this fact is not observed in the present case. On the contrary, silica and alumina are highest in the first layer. The immobility of iron is a peculiar feature of this type. Within limits the $SiO_2 : Al_2O_3$ ratio is constant throughout the profile. These are the chief characteristics of calcium soils and the presence of the *kankar* layer in the lower depths is probably responsible for these factors. The absence of this layer in Type I made silica and sesquioxides a bit mobile. In the case of the whole soil, however, the ratio $SiO_2 : Al_2O_3$ shows a slight leaching of silica as compared to alumina (Table VIII).

Type III

Morphological. This profile has developed as a result of restricted drainage and was situated in an area which was comparatively low lying.

TABLE XI

Ultimate analysis of clay

Profile No. 3

Horizons	SiO_2 per cent	R_2O_3 per cent	Fe_2O_3 per cent	Al_2O_3 per cent	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
0 in.—10 in.	44·61	36·81	11·11	25·70	2·31	2·95	3·63
10 in.—2 ft. 3½ in.	42·55	33·80	11·30	22·50	2·43	3·22	3·12
2 ft. 3½ in.—3 ft. 9 in.	43·42	34·66	10·90	23·76	2·40	3·11	3·42
3 ft. 9 in.—4 ft. 10½ in.	39·77	32·04	10·00	22·04	2·38	3·07	3·46
4 ft. 10½ in.—6 ft.	43·02	34·69	11·10	23·59	2·39	3·10	3·33

TABLE XII

Visual characters

Profile No. 4

Horizons	Depths	Sample depths	Description
I	0 in.—4 ft.	0 in.—1 ft. 5 in. 1 ft. 5 in.—3 ft. 3 ft.—4 ft.	Deep black hard stiff clay; cracks on wetting; sticky and impervious. No reaction with HCl in the top layers, but slight reaction in the bottom
II	4 ft.—5 ft. 5 in.	4 ft.—5 ft. 5 in.	Compact *bajri* (clay interspersed with lime nodules) of grey colour vigorous reaction with HCl

The colour of the soil is deep black and the soil is very clayey. No very sharp colour distinctions between the different horizons were obtainable. The soil shows calcareous nature, specially in the bottom layers.

As will be shown presently, the first and third layers are comparatively more clayey. This has resulted in greater accumulation of sesquioxides, particularly alumina, in these layers as compared to the second and the fourth. Insoluble residue decreases with depth. Soluble silica also decreases with depth. Moisture is more or less uniform throughout, but is decidedly higher than in Types I or II. This indicates higher hygroscopicity of this type as a result of greater clay content, Lime has accumulated

in lower layers although the distribution of magnesia is irregular. Water-soluble salts are slightly high, being nearly 0·1-0·2 per cent with a tendency to accumulate with depth.

TABLE XIII

Analysis of hydrochloric acid extract

(Per cent air-dry basis)

Profile No. 4

Particulars	0 in.—1 ft. 5 in.	1 ft. 5 in.—3 ft.	3 ft.—4 ft.	4 ft.—5 ft. 5 in.
Moisture	4·06	4·42	4·35	3·47
Loss on ignition	3·75	3·89	3·93	4·46
Total insolubles	74·42	74·45	70·28	64·53
SiO_2	25·84	20·02	20·49	17·13
Sesquioxides	15·26	13·46	16·03	12·97
Fe_2O_3	5·52	5·68	6·04	5·32
Al_2O_3	9·68	7·71	9·88	7·51
CaO	1·15	1·15	2·40	7·50
MgO	2·43	1·57	1·83	2·07
K_2O	0·62	0·66	1·24	1·00
P_2O_5	0·06	0·07	0·11	0·14
Total water solubles	0·08	0·10	0·10	0·22

TABLE XIV

Mechanical analysis (2 mm. sample)

(Per cent air-dry basis)

Profile No. 4

Particulars	0 in.—1 ft. 5 in.	1 ft. 5 in.—3 ft.	3 ft.—4 ft.	4 ft.—5 ft. 5 in.
Coarse sand	6·89	10·01	6·37	4·91
Fine sand	25·24	23·21	21·57	31·96
Silt	24·20	24·80	25·90	29·15
Clay	43·30	40·75	43·40	37·20

The predominantly clayey character of the soil is clear from the results of its mechanical analysis tabulated in Table XIV. The clay and silt content is over 60 per cent throughout. This confers on the soil its distinguishing character of cracking when wet and forming big fissures on drying. The first and the third layers are slightly more clayey than the second and the fourth. The physico-chemical data are presented in Table XV.

TABLE XV

Physico-chemical analysis

Profile No. 4

Particulars	0 in.—1 ft. 5 in.	1 ft. 5 in.—3 ft.	3 ft.—4 ft.	4 ft.—5 ft. 5 in.
Moisture (natural) per cent	15·75	20·27	20·16	23·36
Moisture equivalent per cent	35·6	35·9	31·5	31·2
Moisture-holding capacity per cent	48·57	43·46	50·05	40·33
*p*H in *N*-KCl	6·7	7·3	7·3	7·2
Total nitrogen per cent	0·031	0·022	0·017	0·015
Total carbon per cent	0·50	0·46	0·39	0·14
C/N ratio	16·1	20·9	22·9	9·3
Total exchangeable bases m.e. per cent	25·64	30·82	66·49	96·92
Total exchangeable calcium per cent	25·04	25·12	24·16	17·92
Per cent Ca of the total exchangeable bases	97·7	81·5	36·4	18·5

Natural moisture is high, showing better water-retentivity of the soil; and greater moisture-equivalent figure suggests higher colloidal content. *p*H is on the whole neutral and tends to become alkaline with depth. Nitrogen is very low and organic matter is fairly high, thus giving a wider C/N ratio. The higher colloidal content confers on the soil greater base status and the total exchangeable bases are, therefore, fairly high and increase downwards. Exchangeable calcium is better in the first two layers, giving per cent saturation with this cation as 97 and 81, than in the bottom layers where it decreases rapidly reaching such a low value as 18·5. This decrease in the calcium saturation of the exchange complex of the soil with depth makes the subsoil more impervious to water and interferes with its natural drainage. The top layers, however, do not show any degradation of the exchange complex with respect to calcium. As in other cases the separated clay fraction was analysed for its constituents after fusion with sodium carbonate and the results obtained are presented in Table XVI.

The analytical results of the first two layers suggest that there is migration of silica and sesquioxides from the first to the second layer. Below the second layer, however, both silica and sesquioxides become within limits constant. $SiO_2 : R_2O_3$ and $SiO_2 : Al_2O_3$ ratios decrease

TABLE XVI

Ultimate analysis of the clay fraction

Profile No. 4

Horizon	SiO_2 per cent	R_2O_3 per cent	Fe_2O_3 per cent	Al_2O_3 per cent	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
0 in.—1 ft. 5 in.	40·81	30·88	9·40	21·48	2·52	3·23	3·60
1 ft. 5 in.—3 ft.	50·39	39·43	11·24	28·19	2·49	3·06	4·04
3 ft.—4 ft.	36·31	28·40	7·80	20·60	2·41	2·99	4·14
4 ft.—5 ft. 5 in.	34·13	28·43	8·00	20·43	2·28	2·84	4·01

with depth, showing greater mobility of sesquioxides, particularly alumina, with respect to silica. These results become quite interesting when compared with those obtained for Type I (Table VI) where both $SiO_2 : R_2O_3$ and $SiO_2 : Al_2O_3$ ratios are found to increase with depth showing greater mobility of silica. $Al_2O_3 : Fe_2O_2$ ratio increases in the second layer and then becomes constant.

General discussion

A joint consideration of the data presented for the three genetic types of soil described in the present paper points clearly to the fact that climate has played a great part in the development of the soils of the Bundelkhand tract. The intensely hot summers followed by heavy undistributed rainfall during greater part of the monsoons considerably favour weathering and consequent leaching away of the weathered products. This fact coupled with the peculiar topography of the region gives rise to entirely different types of soil formed under heavy, partial and restricted drainage. The soils formed under free drainage are completely devoid of the more soluble constituents like alkali metals, and more or less complete removal of alkaline-earth metals also takes place. There is a further tendency towards leaching of silica and consequent laterization. However, the silica : alumina ratio is too high to permit their classification under laterites. The colour of these soils is red, and they are usually met with on elevated spots.

With a slight restriction in drainage as a result of topography alkaline-earth metals accumulate in the lower horizons and the mobility of silica and sesquioxides is also checked. Under impeded drainage an altogether different type of soil is produced which has a black colour and is highly clayey. The formation of these three types can, therefore, be explained on the basis of the topographical conditions of the locality. Thus red soils (Type I) are found at elevated spots, brown soils (Type II) on level plains and black soils (Type III) in valleys and depressions. The great part played by topography in the formation of the soils of the Deccan canal area was similarly shown by Basu and Sirur [1938] and in the case of those of the Kumaon Hills by Mukherji and Das [1940].

Basu and Sirur in the course of their studies on the soils of the Deccan canal area showed a parallelism between those soils and the Russian tschernozems and called the Deccan canal soils as 'tropical immature tschernozems'. The Bundelkhand soils studied in the present paper also look quite similar to the soils studied by Basu and Sirur, and a brief comparison between the two may be quite interesting.

Basu and Sirur divided the Deccan canal soils into two broad sub-divisions, viz. (a) soils formed under free drainage and (b) soils formed under restricted drainage. It seems that Type I of the present studies has not been met with in the Bombay-Deccan by these workers. Type II closely resembles the 'H type' of Basu and Sirur although there are certain minor points in which the two soils differ. H type of Basu and Sirur has a very shallow depth and the soils are more clayey and have a greater salt concentration than those of the Bundelkhand soil represented by Type II. The total base-saturation capacity is higher for Bombay soils of H type although the per cent saturation with calcium is lower as compared with Type II of Bundelkhand. It seems that the higher water-table (12 ft.) in Bombay is probably responsible for these differences, since in Bundelkhand the water-table where the present type of soils occur is never less than 30 ft.

Type III described in the present paper resembles to some extent the features of type B or C of Basu and Sirur. In the soils studied by these authors, however, considerable quantities of soluble salts were found and the per cent saturation of calcium in the exchange complex was always low. In the present case, soils belonging to Type III neither contain so much soluble salts nor show any degradation of the exchange complex at the surface horizons, although they are not so calcareous as the corresponding soils of the

Bombay-Deccan formed under restricted drainage. These differences have rather important bearing on the agricultural aspects of these soils, since in the Bundelkhand tract degraded black soils are never very common and the problem of '*chopan* formation' found in the Bombay-Deccan is seldom serious. This may be due to the fact that intensive canal irrigation has not as yet been introduced in Bundelkhand and dry farming is still practised in that locality.

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SUMMARY

Four soil profiles developed under semi-arid conditions have been examined near Jhansi in the Bundelkhand tract.

The morphological, chemical and other data for these profiles have been presented and discussed.

Topography has been found to modify not only the colour of the soils, but also their texture and composition.

The SiO_2/Al_2O_3 ratio was about 3·2 in the clay fraction of each type and did not show any appreciable variation with depth.

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A FIELD METHOD OF DETERMINING CLAY CONTENT OF SOILS

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The clay fraction is the most important constituent of soils and its estimation in a simple way, which could be adopted as a field method, has been under examination. The Chiano-Hydrometer [Puri and Puri, 1939] is the most suitable apparatus for the detailed examination of the mechanical composition of soils. It is, however, essentially a laboratory method, with limited application in the field. As the detailed mechanical analysis is not needed for most purposes the development of a field method by which only the clay fraction could be estimated was considered desirable.

Turbidity of a clay suspension has been used as a measure of its concentration. The well-known nephelometer method consists in comparing the turbidity of the unknown suspension with that of the standard. As this apparatus is too elaborate it is not suitable for the purpose in view. A simple method that suggests itself is to lower an object gradually in a largely diluted clay suspension till it becomes invisible to the eye placed at a certain distance above the suspension. A standard clay suspension can be used for calibrating such an apparatus. The greater the concentration of the suspension the smaller will be the distance *d*, through which the object will have to be lowered. There may not, however, be any simple proportionality between the clay percentage and *d* as there may be an enhancement of visibility due to scattering of light as the concentration is increased.

Apparatus

The apparatus consists of a thin steel wire about 1 ft. long fixed at the upper end to a Vernier scale arrangement and at the lower end to a small thin circular metallic disc about 1 in. in diameter with a hole in the centre. The disc is coated with white enamel on which a circle is drawn with black ink. The black circular line with white enamel as the background serves as an excellent 'object' to be viewed. The Vernier scale arrangement is capable of two independent movements by means of two screws. One screw is adjusted till the disc just touches the surface of suspension. The Vernier scale then reads zero. The wire is then lowered gradually by working the second screw till the dark line becomes just invisible. The distance through which it has been lowered, is read by means of the Vernier scale arrangement accurate up to 1/10th of a mm.

Experimental

In order to find the relation between *d* and the clay content of a soil, varying concentrations (0·1, 0·2, 0·3, 0·4, 0·5, 0·6, 0·7, 0·8, 0·9 and 1·0 per cent) of a soil (Lab. No. P.C. 13) were prepared. As this soil contains 55 per cent of clay and as in the proposed method we shall prepare one per cent suspension, the above suspensions may be regarded as equivalent to 5·5, 11·0, 16·5, 22·0, 27·5, 33·0, 38·5, 44·0, 49·5 and 55·0 per cent of clay respectively in the original soil. The clay was separated in each case by pipetting 50 c.c. of the suspension from 5 cm. depth after allowing the appropriate time of settling. This volume was then diluted to 500 c.c., put into a fairly wide cylinder, shaken and the disc lowered into it. The values of *d*, determined in this way, are given in Table I against the clay percentage of the suspensions. These values when plotted would give a smooth curve which can serve as the basic curve for all clay determinations.

Table I

Relation between clay percentage and distance (d) *through which the object is lowered*

Clay percentage	*d* (cm.)
5·5	14·22
11·0	8·40
16·5	4·54
22·0	3·83
27·5	3·26
33·0	2·90
38·5	2·82
44·0	2·76
49·5	2·72
55·0	2·66

In order to determine clay contents of soils one per cent suspensions are prepared, clay separated and diluted in the above manner and values of *d* determined in all cases. The percentage of clay is read from the basic curve corresponding to the value of *d* determined in each case. Clay contents of 100 soil samples were determined by the pipette method as well as by the proposed method. In Table II are recorded the differences between the values

given by the pipette method and the proposed method against the number of soils showing that difference. It will be seen that the proposed method compares very well with the standard pipette method and could be adopted in field laboratories. Precautions such as lowering the disc in the middle of the cylinder, using similar types of cylinders, keeping the eye always, as far as possible, at fixed distance above the suspension, would suggest themselves.

TABLE II

Comparison of the proposed method with the standard pipette method

Difference between percentages found by two methods	Number of soils showing the difference
3	9
2	17
1	40
0·5 and less	34

SOURCES OF ERROR AND THEIR DISCUSSION

Soils with high clay contents. It would appear from Table I that where soils rich in clay are concerned, the method becomes less sensitive. It has been found, however, by experience that the point at which the 'object' becomes invisible in such cases is very sharp and d can be determined with a greater degree of precision. If desired, the method may be modified in this way that when d determined in the case of a soil, corresponds to more than, say, 35-40 per cent of clay, then the diluted suspension may be further diluted with an equal volume of water and the value of clay determined for this suspension may be multiplied with two. Or in the alternative if a soil is considered at the outset to contain more than 35-40 per cent of clay then 0·5 per cent of the suspension may be prepared initially instead of 1 per cent or, 25 c.c. of the clay may be pipetted instead of 50 c.c. from 1 per cent suspension and diluted to 500 c.c. The values determined in such cases from the curve will have to be multiplied by 2.

In Table III results of clay contents of soils, containing above 40 per cent of clay, as determined by the original method as well as by the three modifications suggested above are given and compared with those obtained by the usual pipette method. The agreement is fairly close and it appears that in some cases even no modification is needed.

Variations in the intensity of light. It was felt that the variations in intensities of light at different times and in different places may affect the values of d, thereby introducing errors in estimations of clay contents. In order to get a rough comparison of the intensities of light, a special apparatus, consisting essentially of a small metallic box with two slits having independent shutters on either side was devised. Small pieces of P.O.P. papers were inserted in each of the two apertures by temporarily sliding the shutters on the back side. One piece was exposed directly to sunlight by sliding one of the front shutters for 15 seconds. The tanning acquired by this served as a standard. The second piece was then exposed to the light whose intensity was required. The time which this paper took to acquire the same tanning was noted. The 'standard' paper alongside was occasionally viewed by moving the shutter for a second or so for the purpose of comparison. It may be mentioned that as P.O.P. papers are not sensitive to any appreciable degree in the diffused light, occasional exposures of the 'standard' papers for a second or two in the diffused light of the room would not affect its tanning previously acquired on exposure to sunlight. In this way by determining the time of exposure needed in different lights to get standard tanning on P.O.P. papers, their intensities were compared. This, though no doubt a rough method, served to give some idea of the intensities of light.

The basic curve between d and clay percentage (Table I) was determined in light whose intensity corresponded to 15 minutes' exposure. Observations were then taken with the same concentrations of P.C. 13 soil in six different places where times of exposure needed were 4, 6, 18, 62, and 77 minutes. The values for clay as determined with reference to the basic curve, are given in Table IV.

TABLE III

Comparison of clay contents by different modifications

Soil No.	Clay percentage				
	Original method	I Modification	II Modification	III Modification	Pipette method
P.C. 13	57·0	53·6	54·0	55·0	55·0
P.C. 123	..	74·6	75·8	72·8	79·7
P.C. 145	43·6	39·5	39·8	38·5	41·2
P.C. 146	42·5	39·6	44·0	43·6	44·0
P.C. 147	..	60·8	61·5	63·4	62·0
P.C. 141	54·0	48·6	46·0	46·8	47·5
P.C. 148	55·0	50·2	50·9	51·7	48·1

TABLE IV

Effect of different intensities of light on clay content

Percentage of clay as plotted on the basic curve prepared in light of intensity corresponding to 15 minutes' exposure	Percentage of clay as determined in lights corresponding to the following times of exposures					
	4 min.	6 min.	8 min.	34 min.	62 min.	77 min.
5·5	5·5	5·8	5·2	6·0	5·5	4·8
11·0	11·6	11·0	11·0	11·8	11·5	11·0
16·5	16·4	16·8	16·8	16·4	16·8	17·0
22·0	20·3	21·2	22·0	22·0	22·0	22·8
27·5	28·0	28·0	27·8	28·0	29·0	27·8
33·0	33·8	33·5	34·0	33·8	33·8	35·0
38·5	38·5	40·0	40·8	41·5	40·5	41·0
44·0	46·0	46·8	44·0	46·8	44·0	46·0
49·5	51·0	52·0	52·5	52·5	52·5	52·5
55·0	55·0	57·0	57·0	57·8	57·0	58·0

It will be seen that differences in the values of clay obtained by making observations in different intensities of light are very small except when clay contents are rather high but even for these the agreement is not so bad. But as in soils with high clay percentage, further dilution has been suggested and as extremes of intensities of light are to be avoided, the method is practically free from any serious error. In this connection the following points may be emphasized :

(*a*) The experiments should be conducted in diffused daylight in a room or otherwise covered place. In open space the glare of light reflected from the liquid interferes with the observations.

(*b*) The extremes of intensities of light should be avoided. For example, if the basic curve is prepared in light the intensity of which corresponds to 15 minutes' exposure, experiments should not be conducted in lights whose intensities correspond to more than 60 minutes or less than 3 minutes' exposures.

(*c*) It would be better to conduct determinations in the same room where readings for the preparations of the basic curve are taken.

Personal error. This can be eliminated if the basic curve is prepared by the observer himself. In Table V values obtained for 12 soils by two persons are given. The basic curve was prepared by one of them.

Different colours of soils. The colour of the suspension would appear at first sight to affect determinations by this method, but as the suspension is very dilute, the colour factor does not influence the results. In Table I soils selected were of all colours available. The agreement between clay contents as determined by the pipette method and the proposed method rules out any possibility of error on account of this factor.

TABLE V

Magnitude of personal error in clay estimation

Soil No.	Percentage of clay	
	Determined by A	Determined by B
P. C. 271	17·0	15·2
P. C. 230	27·0	24·6
P. C. 247	12·6	10·8
P. C. 255	14·6	13·0
P. C. 283	14·6	17·0
P. C. 285	16·6	18·2
P. C. 286	30·5	27·2
P. C. 287	20·2	20·5
P. C. 288	25·0	25·0
P. C. 290	12·8	10·5
P. C. 291	17·8	20·0
P. C. 292	23·5	22·5

SUMMARY

A simple method which can be easily adopted in field laboratories for finding clay contents of soils is described. It consists in measuring the turbidity of a diluted clay suspension with reference to standard suspensions by lowering gradually an object in the suspension till it becomes invisible to the eye placed vertically above the suspension at a convenient distance. Various sources of error are discussed.

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THE OCCURRENCE AND SIGNIFICANCE OF TRACE ELEMENTS IN RELATION TO SOIL DETERIORATION

I. MANGANESE

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Certain elements, viz. boron, iron, manganese, etc. although present in soils in relatively small amounts are known to exercise a profound influence on the growth and yield of crops. Manganese occupies rather a conspicuous position among this class of elements and numerous studies of its roll in soils are described in literature. The classical work of Bertrand and Rosenblatt [1921] brought out that manganese is invariably present in plants and is essential for their normal development. McGeorge [1923] and Bertner [1935] had shown that if manganese is present in excess, to that sufficient for the normal growth of plants, it is known to have toxic effects.

Very little work had so far been done in India in connection with the occurrence of trace elements in soils. Quite recently Hoon, Dhawan and Madan [1941] examined soils from various districts of the Punjab for their trace elements content in relation to the yield of wheat. As a result of that investigation, significant correlations were shown to exist between the contents of manganese and available phosphates respectively in soils and the yield of wheat, but no significant correlation between the total soluble salt content and a low and insignificant correlation between the pH and yield of wheat were obtained. The present paper is intended to throw some fresh light on the occurrence and significance of manganese in the Punjab soils with special reference to soil deterioration.

Experimental

The method proposed by Iyer and Rajagopalan [1936] was adopted for the determination of manganese in soils. In the case of water samples a known volume was evaporated and the manganese determined in the residue. The pH of 1 : 5 soil suspensions and water samples was determined by the glass electrode according to Hoon and Taylor [1931]. The other analyses reported in this paper were done by the usual methods.

Soil profiles from areas with low water-table

The Punjab alluvium being relatively a recent formation a well-developed soil profile showing horizons of eluviation and illuviation, as characterize the soils of the hilly areas receiving high precipitation, is seldom met with. However, due to the arid climatic conditions prevailing in the Punjab, certain characteristics are developed which frequently influence structural or colour changes in the soil profile. Therefore in the absence of well-marked genetic horizons in the profile, soil samples were taken at known depths along the profile up to the water-table from a number of places and analysed for their manganese content. The results of the manganese content of a few soil profiles from areas with low water-table are given in Table I. It is brought out that manganese can be traced throughout the depth of the profile with slight but distinct accumulation in certain sections. This observation was at variance with those made by Kelley [1912] in connection with his study of the Hawaiain soils that the manganese content decreased from the surface downwards. It may be pointed out here that the manganese contents given in Table I are not of that high order reported by other investigators but as shown by Hoon, Dhawan and Madan [1941]. Manganese even in such amounts manifested a fairly significant and negative correlation with the yield of wheat in the Punjab. It was a matter for further study whether the effect of manganese on the yield of wheat was direct or indirect due to some other factor which determined the accumulation of manganese in the soil.

Manganese content of subsoil water samples

Pits were dug down to the water-table at a number of positions in certain reclamation areas, viz. Amirpura (125 acres), Maharanwala (13 acres), Chakanwali (3,400 acres waterlogged) and Raniwah Drain areas and samples of subsoil water taken from the bore-holes. These samples were analysed for their total soluble salt and manganese contents and pH. The results of analyses given in Table II show that the subsoil water samples taken from a number of sites in the same area manifest considerable differences in their soluble salts and manganese contents. It means that the subsoil flow in the Punjab alluvium is considerably impeded. However, a high soluble salt content of the water samples is invariably associated with a high manganese content. In areas where the water-table is within 3-4 ft.

TABLE I

Results of the manganese content of soil profiles taken from a low water-table area (Jhak Ditta Chak No. 433 G. B.)

Soil profile taken from Sq. No. 31/54			Soil profile taken from Sq. No. 56/47			Soil profile taken from Sq. No. 55/46 Field No. 1		
S. No.	Depth	Manganese content in milliequivalents per 100 gm. of soil	S. No.	Depth	Manganese content in milliequivalents per 100 gm. of soil	S. No.	Depth	Manganese content in milliequivalens per 100 gm.t of soil
1	0—6 in. .	3·85	1	0—6 in. .	2·30	1	0—6 in. .	3·70
2	6—12 in. .	2·95	2	6—12 in. .	2·40	2	6—12 in. .	3·90
3	1—2 ft. .	2·55	3	1—2 ft. .	2·35	3	1—2 ft. .	3·60
4	2—3 ft. .	4·30	4	2—3 ft. .	2·65	4	2—4 ft. .	2·90
5	3—4 ft. .	3·60	5	3—4 ft. .	1·80	5	4—5 ft. .	2·90
6	4—6 ft. .	2·40	6	4—5 ft. .	1·10	6	5—7 ft. .	2·80
7	6—8 ft. .	2·85	7	5—6 ft. .	2·20	7	7—8 ft. .	3·00
8	8—9 ft. .	3·10	8	6—7 ft. .	2·00	8	8—10 ft. .	2·90
9	9—10 ft. .	3·35	9	7—8 ft. .	2·25	9	10—11 ft. .	2·30
10	10—11 ft. .	3·05	10	8—9 ft. .	2·65	10	11—12 ft. .	2·70
11	11—12 ft. .	2·75	11	9—10 ft. .	2·50	11	12—13 ft. .	2·50
12	12—13 ft. .	2·75	12	10—11 ft. .	2·25	12	13—14 ft. .	2·80
13	13—14 ft. .	2·90	13	11—12 ft. .	2·75	13	14—15 ft. .	2·80
14	14—15 ft. .	4·20	14	12—13 ft. .	2·90	14	15—16 ft. .	2·30
15	15—16 ft. .	4·00	15	13—14 ft. .	2·90	15	16—17 ft. .	3·50
16	16—17 ft. .	3·80	16	14—16 ft. .	2·50	16	17—18 ft. .	2·70
17	17—18 ft. .	3·00	17	16—17 ft. .	2·70	17	18—19 ft. .	2·70
18	18—19 ft. .	3·40	18	17—19 ft. .	2·10	18	19—20 ft. .	3·00
19	19—20 ft. .	2·35	19	19—20 ft. .	2·15	19	20—21 ft. .	3·65
20	20—21 ft. .	2·30	20	20—21 ft. .	2·50	20	21—22 ft. .	4·00
21	21—22 ft. .	2·60	21	21—22 ft. .	1·90	21	22—23 ft. .	2·50
22	22—23 ft. .	1·80	22	22—23 ft. .	2·05	22	23—24 ft. .	1·50
23	23—24 ft. .	1·95	23	23—24 ft. .	1·95	23	24—25 ft. .	1·10
24	24—25 ft. .	1·95	24	24—25 ft. .	1·75			

from the surface the total soluble salt content of water is very low and there is little manganese in the subsoil water. This may be attributed to reduced impedence in the flow of water under high water-table conditions.

Manganese content of soils in relation to productivity

From the data of yield of major agricultural crops a few sites were roughly classed as good, average and poor. Soil samples were taken at those sites and a comparison of their manganese content made. The results of analyses are given in Table III. This study shows that there is relatively a higher manganese content in soils representing areas having poor yield of crops than those taken from areas with good or average yield. The difference in the manganese content is more pronounced in the top 3-4 ft. portion of the various soil profiles examined.

It is admitted that in case of soils representing poor crop yield the pH is definitely high and in certain cases the total soluble salt content is high and these might also contribute to low crop yield. It has been shown by Hoon and Dhawan [1940] that soils having high pH, if subjected to electrodialysis, yield more manganese in soluble form than soils of low pH. Moreover, the major portion of electrodialysable manganese separates in the beginning. It is not surprising, therefore, that in soils of high pH more manganese comes out in the soluble form and thus, becoming available to plants in quantities greater than their normal requirements, inhibits their growth. Further, this availability of manganese is reduced when the dominant base in the exchange complex of soil is calcium. Total soluble salts when present in high concentrations, as reported for certain cases in Table III, also affect the yield adversely. But, as pointed out by Hoon, Dhawan and Madan [1941], the correlation in the case of manganese was more significant than either of those of pH or total soluble salts in relation to the yield of wheat in the Punjab.

TABLE II

Results of analyses of subsoil water samples taken from different reclamation areas

S. No.	Name of site	*p*H	Parts per 100,000 parts of water		Remarks
			Total soluble salt content	Manganese content	
1	Amirpura reclamation site	9·01	984·8	182	
2	Ditto	7·90	334·8	Traces	
3	Ditto	8·86	498·2	55	
4	Ditto	8·43	280·6	40	
5	Ditto	7·67	214·4	51	
6	Ditto	7·87	114·4	81	
7	Ditto	7·30	53·8	nil	
8	Ditto	7·14	76·6	nil	
9	Ditto	7·34	71·2	nil	
1	Mehranwala reclamation site	8·12	532·2	66	
2	Ditto	7·18	208·2	18	
3	Ditto	7·35	292·2	30	
4	Ditto	7·92	2489·1	106	
5	Ditto	8·42	2279·6	105	
6	Ditto	7·85	363·6	62·6	
7	Ditto	8·22	149·8	22·6	
8	Ditto	7·64	766·4	72	
9	Ditto	7·56	312·0	32	
10	Ditto	8·34	135·9	16	
1	Lower Raniwali drain area	7·12	407·0	48	
2	Ditto	8·55	280·2	66	
3	Ditto	7·18	162·0	64	
4	Ditto	6·73	512·6	92	
5	Ditto	6·60	549·6	150	
1	Chakanwali reclamation farm	7·38	38·5	nil	Waterlogged site (water-table within 3-4 ft. from surface)
2	Ditto	7·42	18·8	nil	Ditto
3	Lil Village on U.C. Canal	7·32	27·30	nil	Ditto
4	Plac? near chichoki mallian	6·76	54·50	0·43	Ditto

During the course of the soil surveys it was observed that different types of naturally growing flora get established at various places. An examination of soils with reference to the type of flora borne on them had revealed that some types of flora, at any rate, might serve as indicators of the development of certain special characteristics in the soils [Hoon, Dhawan and Mehta, 1939; Hoon and Mehta, 1937]. As an illustration, one case of such typical flora may be cited. *Lani* (*Suaeda fruticosa*) grows profusely, to almost exclusion of all other types of natural flora, on land representing a fairly advanced stage of deterioration. Such land can be classed as uneconomic from the point of view of agricultural development or reclamation. With advancing deterioration such *lani*-bearing areas, in course of time, become devoid of all vegetation and develop into bare batches. Soil samples taken from areas bearing *lani* and devoid of vegetation were analysed for their manganese and total soluble salt contents and *p*H. The results of analyses are given in Table IV. It is shown that such areas have a high manganese content, soils representing areas devoid of vegetation having more manganese than those taken from *lani*-bearing areas. Another characteristic difference in the manganese content of soils from those two areas is that, whereas the manganese content in the top portions of the profiles representing *lani* is less than the underlying portions, that in profiles from areas devoid of vegetation is high throughout the whole profile. Incidentally again, the soils from these two types of

TABLE III

Results of analyses of soil samples with reference to the cropping condition at the sites

S. No.	Description of site, etc.	Depth of soil sample	Per cent total soluble salt content	*p*H	Manganese content in milliequivalents per 100 gm. of soil	Classification of land on the basis of productivity of major agricultural crops, i.e. good, average or poor
1	Field No. 3860 Mahrunwali	0—7 in.	0·11	7·98	0·75	Good
2		7—26 in	0·07	7·94	1·05	
3		26—44 in.	0·33	8·00	2·00	
4		44—50 in.	0·09	7·86	0·70	
1	Field No. 2130 Mahrunwali	0—6 in.	0·16	7·99	1·30	Good
2		6—12 in.	0·14	7·77	1·30	
3		12—24 in.	0·14	7·82	1·10	
4		24—36 in.	0·14	8·04	1·40	
1	Field No. 2710 Mahrunwali	0—3·5 in.	0·14	8·05	0·75	Average
2		3·5—21 in.	0·11	7·95	1·20	
3		21—42 in.	0·11	8·10	1·20	
4		42—53 in.	0·13	7·57	2·85	
5		53—64 in.	0·11	8·27	1·20	
1	Field No. 2710 Mahrunwali	0—¾ in.	1·05	7·62	2·75	Below average
2		¾—5 in.	1·11	8·40	2·75	
3		5—27 in.	1·00	8·53	4·30	
4		27—46·5 in.	0·17	8·44	1·90	
5		46·5—55 in.	0·25	9·58	2·80	
6		55—74 in.	0·20	8·85	2·30	
1	Plot 20 Ajudhiapur	0—6 in.	1·69	10·46	4·00	Poor
2		6—12 in.	1·35	10·44	4·00	
3		12—24 in.	1·00	10·40	3·40	
4		24—36 in.	0·66	10·28	2·70	
1	Plot 9 Ajudhiapur	0—6 in.	0·18	9·47	3·90	Poor
2		6—12 in.	0·10	8·60	4·90	
3		12—24 in.	1·09	9·28	4·90	
4		24—36 in.	0·59	9·84	4·05	
1	Rakh Amanat Sarai (Thur Area)	0—3 in.	..	9·60	4·35	Poor
2		3—6 in.	..	9·80	4·55	
3		6—13 in.	..	10·20	4·60	
4		13—32 in.	..	9·90	4·70	
1	Amirpura Field No. 446 Bl.	0—6 in.	..	9·56	4·10	Poor
2		6—12 in.	..	10·10	4·55	
3		12—24 in.	..	10·02	5·25	
4		24—36 in.	..	9·97	4·35	

areas have a very high *p*H which confirms the statement made in the earlier part of this paper and in a previous publication [Hoon and Dhawan, 1940].

Manganese content of soils in relation to their mechanical composition

An accumulation of manganese in certain sections of the soil profiles occurs as pointed out in preceding sections. Robinson [1929] showed that manganese occurred in soils largely as manganese dioxide concretions concentrated in the sand and silt fractions and the bulk of exchangeable manganese was located in the colloidal fractions. An examination was made to bring out if the accumulation of manganese in the soils under reference manifested any relation to their mechanical composition. Although it was not possible to determine the proportion of manganese in the form of concretions and exchangeable separately, as reported by Robinson, but the results of the total manganese content and mechanical analysis

of soils are given in Table V. It is shown that, in general, an increase in the silt and clay fractions (particles below 0·02 mm.) is accompanied by an increase in the manganese content of soils and vice versa. It seems, therefore, that as far as the presence of manganese in the soils of the Punjab is concerned the major part occurs in the exchangeable form rather than as concretions concentrated in sand fraction. That also accounts for the comparatively low content of manganese reported for the Punjab soils than those reported by other investigators for some special manganiferous soils in other parts of the world.

TABLE IV

Results of analyses of soil samples from deteriorated areas

S. No.		Type	Depth	Per cent total soluble salt content	*p*H	Maganese content in milliequivalents per 100 gm. of soil
A	1	Profile taken from an area under *lani* (*Suaeda fruticosa*).	0—4 in. . .	2·46	9·76	2·15
	2		4—16 in. . .	0·19	10·15	3·25
	3		16—24 in. . .	0·13	9·87	2·00
	4		24—36 in. . .	0·11	9·64	4·00
B	1	Ditto . . .	0—2½ in. . .	1·16	8·97	1·95
	2		2½—11 in. . .	0·57	9·48	4·40
	3		11—22 in. . .	0·53	9·41	3·00
	4		22—33 in. . .	1·15	9·11	3·20
	5		33—48 in. . .	0·83	9·24	3·20
C	1	Profile taken from an area devoid of vegetation	0—½ in. . .	0·13	9·07	4·05
	2		½—3½ in. . .	0·61	9·64	4·95
	3		3½—26 in. . .	0·51	9·82	5·10
	4		26—36 in. . .	0·23	9·64	4·60
D	1	Ditto . . .	0—½ in. . .	0·84	9·28	3·20
	2		½—7 in. . .	1·18	9·70	4·40
	3		7—18 in. . .	0·99	9·79	3·70
	4		18—32 in. . .	0·61	10·90	4·00
	5		32—48 in. . .	0·43	10·00	3·60

The occurrence of kankar (*calcium carbonate: soil concretions*) *in the Punjab soils in relation to their manganese content*

On account of arid climatic conditions prevalent in the Punjab plains the soils of this part contain varying contents of soluble sodium salts, viz. sodium chloride, sodium sulphate, etc. and are alkaline in reaction. Moreover, at certain places and at certain depths of soil profile *kankar* (nodular calcium carbonate) is met with. The factors governing the formation of *kankar* in soils has not yet been precisely defined. A fluctuating water-table rich in bicarbonate content is considered to be one plausible explanation of the formation of *kankar* in soils [1936].

A few soil profiles from *kankar*-bearing areas were examined for their manganese content. The results of this study are given in Tables VI, VII and VIII. It is brought out that:

(*i*) The manganese content of the soil in the layer where *kankar* nodules are present is comparatively higher than in the layer where they are absent (Table VI).

(*ii*) There is a slight indication of the manganese content of the *kankar* nodules being generally higher than that in the soil present in the *kankar* strata (Table VII).

(*iii*) If the *kankar* nodules were graded according to their sizes, e.g. large, medium and small (pea-sized) then there is a slight indication of differences in the manganese content of *kankar* nodules according to their sizes, the manganese content of the pea-sized *kankar* nodules being relatively greater than that of the large or medium-sized nodules (Table VIII).

The accumulation of manganese in the *kankar* nodules may be attributed to the fact that the formation of *kankar* is associated with the high alkalinity of soil which condition is also conducive to a high manganese content. It is not

unlikely that manganese forms the nucleus for the nodules to grow in size due to the causes not yet clearly defined. This might, however, explain why the percentage of manganese in big-sized *kankar* nodules is comparatively less than in the pea-sized *kankar*.

TABLE V

Results of analyses of a few soil profiles showing the manganese content of soils in relation to their mechanical composition

S. No.	Depth	Mechanical analysis: Per cent sand	Per cent silt	Per cent clay	Min. m.e. per 100 gm. of soil	*p*H
Profile I						
1	0—6 in.	33·9	36·3	20·1	4·6	9·8
2	6—12 in.	43·2	32·0	13·7	3·2	9·6
3	1—2 ft.	51·0	27·0	14·3	2·6	9·7
4	2—3 ft.	42·6	34·0	15·1	3·5	9·5
5	3—4 ft.	47·2	26·0	17·8	2·8	9·1
6	4—5 ft.	60·6	17·9	10·5	2·8	9·7
7	5—6 ft.	56·1	25·7	9·3	3·9	9·4
8	6—7 ft.	62·8	22·2	8·7	2·8	9·6
9	7—8 ft.	39·8	34·9	14·0	4·1	9·5
10	8—9 ft.	60·3	25·1	6·7	2·6	9·5
11	9—10 ft.	76·0	34·3	6·7	3·3	9·5
12	10—11 ft.	66·9	18·6	8·0	2·8	9·4
13	11—12 ft.	79·4	11·9	5·4	2·2	9·2
14	12—13 ft.	79·4	12·9	5·9	2·9	8·7
Profile II						
1	0—6 in.	36·3	27·5	25·6	4·1	9·7
2	6—12 in.	50·6	21·1	17·7	3·2	9·6
3	1—2 ft.	51·9	20·5	16·3	3·5	9·6
4	2—4 ft.	35·5	41·2	15·1	4·1	8·9
5	4—5 ft.	55·7	21·0	13·5	3·5	9·5
6	5—6 in.	55·7	21·2	12·9	3·4	9·5
7	6—7 ft.	69·6	13·6	8·8	2·4	8·8
8	7—8 ft.	74·6	12·3	5·6	2·0	8·8
9	8—9 ft.	66·1	17·3	6·9	3·3	9·0
10	9—10 ft.	54·8	22·1	13·3	3·8	9·6
11	10—11 ft.	51·8	27·4	10·6	3·0	9·0
12	11—12 ft.	25·2	47·2	16·7	4·8	9·1
13	12—13 ft.	44·0	35·7	11·4	4·2	9·2
14	13—14 ft.	61·5	28·3	5·6	3·5	9·3
Profile III						
1	0—6 in.	62·7	19·5	8·1	2·3	9·9
2	6—12 in.	58·7	19·1	15·7	3·3	9·8
3	1—2 ft.	49·4	24·3	20·7	4·9	9·9
4	2—3 ft.	49·8	23·4	21·0	3·9	9·8
5	3—4 ft.	48·9	23·2	20·0	4·3	9·7
6	4—5 ft.	61·6	19·0	11·6	2·7	9·7
7	5—6 ft.	45·0	29·8	13·9	2·9	9·6
8	6—8 ft.	46·3	28·5	15·1	3·2	9·6
9	8—9 ft.	60·3	18·7	10·8	2·0	9·5
10	9—10 ft.	59·6	12·5	16·6	2·1	9·5
11	10—11 ft.	29·5	40·9	20·9	3·0	9·5
12	11—12 ft.	34·9	36·5	17·0	3·0	9·5
13	12—13 ft.	35·4	38·9	15·1	3·3	9·5
14	13—14 ft.	37·9	36·8	13·8	1·6	9·4
15	14—15 ft.	45·6	31·0	11·7	1·6	9·4
Profile IV						
1	0—2 in.	55·4	28·2	11·5	3·2	8·4
2	2—6 in.	66·7	17·4	8·1	2·4	8·4
3	6 in.—3 ft.	94·9	1·0	0·7	2·2	8·5

Table VI

Results of the manganese content of some kankar *bearing soil profiles*

S. No.	Depth	Manganese content in milliequivalents per 100 gm. of soil	Characteristics of soil strata
Profile I			
1	0—6 in.	2·1	
2	6 in.—1 ft.	3·5	
3	1—2 ft.	3·6	
4	2—3 ft.	3·7	
5	3—4 ft.	3·7	
6	4—5 ft.	3·6	*Kankar* zone having small-sized nodules (S. No. 3–10)
7	5—6 ft.	3·9	
8	6—7 ft.	3·9	
9	7—8 ft.	3·2	
10	8—9 ft.	3·5	
11	9—10 ft.	2·1	
12	10—11 ft.	3·0	
13	11—12 ft.	2·7	
14	12—13 ft.	2·6	
15	13—14 ft.	2·6	
16	14—15 ft.	2·5	
17	15—16 ft.	2·2	
Profile II			
1	0—6 in.	2·2	
2	6 in.—1 ft.	2·3	
3	1—2 ft.	2·8	
4	2—3 ft.	3·0	
5	3—4 ft.	3·3	
6	4—5 ft.	3·0	*Kankar* zone having small-sized nodules (S. No. 4–9)
7	5—6 ft.	3·2	
8	6—7 ft.	4·2	
9	7—8 ft.	3·2	
10	8—9 ft.	2·7	
11	9—10 ft.	2·1	
12	10—11 ft.	1·9	
13	11—12 ft.	2·1	
14	12—13 ft.	2·0	
15	13—14 ft.	1·0	Almost sand
16	14—15 ft.	1·8	Coarse sand saturated with subsoil water (S. No. 16–18)
17	15—16 ft.	1·9	
18	16—17 ft.	2·0	
Profile III			
1	0—6 in.	2·0	
2	6 in.—1 ft.	3·1	
3	1—2 ft.	3·0	
4	2—3 ft.	3·6	
5	3—4 ft.	3·6	
6	4—5 ft.	3·4	*Kankar* zone having small and big-sized *kankars* (S. No. 2–10)
7	5—6 ft.	3·2	
8	6—7 ft.	3·7	
9	7—8 ft.	2 9	
10	8—9 ft.	3·4	
11	9—10 ft.	2·4	
12	10—11 ft.	2·8	Fine sand
13	11—12 ft.	2·7	Coarse sand
14	12—13 ft.	2·7	Coarse sand
15	13—14 ft.	1·9	
16	14—15 ft.	1·8	Sand saturated with subsoil water (S. No. 15–17)
17	15—16 ft.	1·4	
18	16—17 ft.	1·6	

Summary

Manganese has been shown to be present in the soil profile right up to the water-table with slight accumulation in certain sections of the profile in areas where the water-table is low. In general an increase in the silt and clay fractions is accompanied by a slight increase in the manganese content of soil and vice versa.

Table VII

Results of the manganese content of kankar *nodules and the soil matrix in some* kankar *bearing soil profiles*

S. No.	Site	Depth	Manganese content m.e. per 100 gm.	
			Kankar nodules	Soil matrix in that strata
Profile I	Chakanwall Reclamation area C/1 plot			
1		0—7 in.	2·8	2·5
2		7—12 in.	4·1	2·8
3		1—2 ft.	2·8	2·6
4		Below 2 ft.	2·9	2·7
Profile II	Do. X/1 plot			
1		0—8 in.	4·8	2·0
2		8—17 in.	3·5	2·5
3		17—28 in.	2·6	1·9
4		28—36 in.	2·6	2·0
Profile III	Do.			
1		0—10 in.	5·2	1·9
2		10 in.—2 ft.	5·4	3·8
3		2—3 ft.	3·4	3·2

Table VIII

Results of manganese content of the different sizes of kankar *nodules and the soil matrix in* kankar *bearing strata of various soil profiles*

S. No.	Manganese content milliequivalents per 100 gm.			
	Soil matrix	Big-sized nodules	Medium-sized nodules	Small-sized nodules
1	3·5	3·0	3·6	5·0
2	2·8	Not present	Not present	37·0
3	2·9	Do.	5·8	7·2
4	3·9	3·6	4·2	8·0
5	4·0	Not present	4·4	4·6
6	4·15	4·0	4·6	6·2
7	3·4	3·6	Not present	4·0
8	3·7	7·5	9·5	13·0
9	3·6	Not present	8·8	11·2

The subsoil water samples from areas having low crop yields have usually higher soluble salt and manganese contents than those from good or average land. Likewise, the soils from the former type of land have comparatively greater manganese content than those from the latter types, the difference being more prominent in the top 4 ft. portion of the profile.

Soils of high pH value are associated with relatively greater manganese content than those with low pH.

A number of soils and subsoil water samples have been analysed for their total manganese content. A qualitative relationship is brought out between the manganese content and fertility of the soils, i.e. good and average soils contain less manganese than bad ones.

The small (pea-sized) *kankar* nodules have a slightly higher manganese content than large or

medium-sized nodules. The soil-matrix in the *kankar*-bearing strata has also slightly higher manganese content than soils in strata where *kankar* is absent.

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PRELIMINARY TREATMENT OF RED SOIL SEPARATES, AS OBTAINED BY MECHANICAL ANALYSIS FOR MINERALOGICAL EXAMINATION

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In course of mineralogical analysis of Indian red soils by petrographic methods, it was observed that soil fractions of different sizes, as obtained by mechanical analysis were more or less red in colour due to adhering iron oxide, which made identification of these soil separates difficult. The fine sand fractions appeared in many cases to consist entirely of iron oxide, although in reality they were composed of diverse minerals with coating of iron oxide hydrated or non-hydrated. Thus the removal of materials which form coating over the minerals is essential before the minerals can exhibit fully their individual optical properties.

Hendrick and Newland [1928] suggested treatment of soil separates with oxalic acid for removal of iron oxide stains. Tamm [1934] advocated use of ammonium oxalate for the same purpose. But it has been observed that even long continued boiling with oxalic acid or ammonium oxalate does not completely remove iron oxide coating in many cases. The use of acid ammonium oxalate is not entirely satisfactory, inasmuch as it takes unduly long time tending to act upon other soil constituents. Truog and others [1936] have fully elucidated the necessity of removal of such interfering materials and have devised a special treatment of soils for mechanical and mineralogical analysis. The sodium sulphide-oxalic acid treatment which they adopted is not free from objections. It requires a long time to be carried out and may attack less resistant materials in soils. In spite of some of its defects the above treatment is an essential supplement to the processes involved in mechanical analysis of soils.

The author has made use of hydriodic acid for removal of adhering free iron oxide and free alumina to the mineral particles in different fractions of red soils obtained by mechanical analysis in which sulphide-oxalic acid treatment has not been included. A perfectly white residue is obtained by keeping the soil separates (1 gm. in 25 c.c. of 10 per cent acid) for two hours on a water bath. The residue may be filtered and washed with water until free from coloured solution of iron oxide in the acid. If the material is not perfectly white by one treatment it should be subjected to a second operation in the same way as the first one. It has been seen that alumina is less easily acted on by this reagent than free iron oxide. Hydriodic acid does not appreciably attack soil constituents other than free iron oxide and free alumina.

A method of estimation of free iron oxide and free alumina in red soils has been found possible by using hydriodic acid. A treatment with this reagent in course of mechanical analysis of soils by alkaline permanganate method evolved by the author [Chakraborty, 1935] seems advisable. These points will form themes of future publication. This reagent may also find useful application in analysis of clays by X-ray.

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STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

IX. THE INTERRELATION OF MANURIAL FACTORS AND WATER-SUPPLY ON THE GROWTH AND YIELD OF 4-F COTTON ON LIGHT SANDY SOILS*

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(With five text-figures)

INTRODUCTION

THE investigations described here had their origin in the discovery of the causes responsible for the bad opening of bolls in the Punjab-American cottons, a phenomenon popularly termed as *tirak*. It has been established that two types of soil conditions are mainly associated with *tirak*. The present studies are in relation to only one of the soil types, namely light sandy soils deficient in nutrients, especially nitrogen.

The growth of plants on such soils is normal in the earlier stages of development and the appearance of deficiency symptoms usually synchronizes with the approach of the reproductive phase. At this stage, the stems of the plants are characterized by the presence of anthocyanin pigments. There is also yellowing of leaves, followed in time by reddening and premature defoliation which intensifies with age. A marked reduction in the number and size of bolls occurs, eventually culminating in poor yields. As a decrease in boll size is accompanied by immaturity of seeds and poor quality of lint, the loss is both quantitative and qualitative.

Premature yellowing of leaves indicates internal starvation for want of one of the essential elements, such as nitrogen, phosphorus, or potassium. Such deficiency symptoms in leaves have been described by various workers in case of other crops as well. Immaturity of seeds in the bolls showing *tirak* further suggests the probability of potash deficiency. From various parts of America, the cotton plant has been reported to show immaturity of seeds when grown on potash-hungry soils.

If these symptoms were directly caused by the deficiency of any one of the essential elements, application of the same should normally prevent the development of such abnormalities, while the use of others would prove ineffective (Liebig's law of the minimum). The effectiveness of one factor may, however, be limited by the level of another factor or factors (the principle of limiting factors). Hence it was necessary to study simultaneous changes in the level of all the three elements (N, P, K) by laying out multiple-factor experiments. For the same reason, the possibility of other factors, such as water-supply and organic manure, modifying the response to any one of the above-mentioned nutrients could not be ignored.

It is not possible to appreciate and understand fully the effects of treatments, if the study is confined to the final yield data alone. Yield is the integration of growth processes and success or failure of any treatment would figure in the developmental records, collected at the different stages of growth. Morphological development is the index of the progress of physiological processes and the influence of disturbing factors, local or general, would appear as depressions or peaks in the normal trend of the curves. By growth-analysis, the nature of the events that lead up to the final yield, can be followed up. Additional information becomes available concerning the shape and form of growth curves. Clearly, therefore, it was important to undertake developmental studies to complete the picture in the present case.

Briefly stated, three features characterize the present investigation. Firstly, the studies have been made in relation to the problem of *tirak*, under known conditions of soil associated with it. Secondly, attention has been paid to the exploration of interactions by laying out factorial designs on modern lines. Thirdly, the studies have been supplemented by the maintenance of developmental records that have provided material for growth analysis.

No published data concerning the effects of fertilizers on the growth, development and yield of cotton, under known conditions of soil are available for the Punjab. A number of replicated single-factor yield trials were, all the same, made by the Department of Agriculture, Punjab [1936],

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Three conclusions emerge from the study of the results of these experiments. Firstly, the effect of nitrogen varied from place to place and season to season. In certain cases, the response was large, in others, meagre. Secondly, application at fruiting, in general, proved better than the one made earlier. According to Crowther [1938] the superiority of the later application is to be attributed to the sandy character of the Punjab soils and to local factors like early shedding of flowers caused by the nondehiscence of anthers. Thirdly, the phosphatic and the potassic fertilizers proved ineffective. Afzal [1941] also refers to the absence of any manurial responses to N, P or K in his experiments at Lyallpur, running consecutively for a period of five years. On the other hand, Crowther [1939] deplored the general apathy in India towards the use of artificials in view of the lower nitrogen content of the soils of this country in comparison with those of Egypt where nitrogenous fertilizers have, in particular, gained great popularity, and increasing returns have invariably been obtained. Recent researches done in the Punjab [Dastur, 1941; Dastur and Singh, 1942] have disclosed the causes for such discrepancies in the effectiveness of nitrogen. It is established that nitrogenous applications produce little effect on soils with saline subsoils. Heavy increases in yield are a feature of the light sandy soils having no subsoil salinity as would be clear from the results presented here. Relative proportions of the two soil types in a particular field would, therefore, determine the magnitude of its responsiveness.

Recently much useful work has been done in Sudan [Gregory *et al.* 1932; Crowther, 1934; Lambert and Crowther, 1935] and in Egypt [Crowther and his associates, 1935-1937] on the interactions of factors on crop growth. It may, however, be pointed out that these comprehensive experiments were laid out irrespective of the soil conditions. The rôle of soil as a master factor modifying the response to nitrogen, under the same climatic conditions, has already been quoted as an instance, and this point should not be lost sight of in comparing the results obtained in Egypt and Sudan with those reported herein.

Investigation

Experiment I (*1937-38*)

A piece of land, covering an area of 6 acres at the Lyallpur Agricultural Farm, where *tirak* symptoms were observed in 1935-36, was selected for this investigation. The soil of this area is light sandy composed of 10-15 per cent clay, 10-20 per cent silt and 65-75 per cent sand fractions. The land was kept fallow and given adequate preliminary cultivation during 1936-37, and was laid out in the succeeding season.

Description of the experiment

Experimental treatments and layout. The entire area was divided into three 2-acre blocks. Each block was subdivided into four main plots to which were assigned at random the four main plot treatments:

$$\begin{matrix}(o)\\(m)\end{matrix} \times \begin{matrix}(w_1)\\(w_2)\end{matrix} = w_1o,\ w_2o,\ w_1m,\ w_2m\,;$$

where o = No organic manure,
m = Farmyard manure at 5 tons per acre,
w_1 = Normal waterings during the growing season, and
w_2 = Heavy waterings during the growing season.

Differentiation of watering started from the first irrigation and was secured by rewatering w_2 plots at an interval of 16-24 hours following the normal course of watering throughout.

Each of the 12 main plots was split up into eight sub-plots for the random distribution of the eight treatment combinations enumerated below:

$$\begin{matrix}(o)\\(n)\end{matrix} \times \begin{matrix}(o)\\(p)\end{matrix} \times \begin{matrix}(o)\\(k)\end{matrix} = o,\ n,\ p,\ k,\ np,\ nk,\ pk,\ npk\,;$$

where o = No fertilizer,
n = Nitrogen at 48 lb. per acre,
p = P_2O_5 at 120 lb. per acre,
k = K_2O at 48 lb. per acre,
np = 48 lb. N + 120 lb. P_2O_5 per acre,
nk = 48 lb. N + 48 lb. K_2O per acre,
pk = 120 lb. P_2O_5 + 48 lb. K_2O per acre, and
npk = 48 lb. N + 120 lb. P_2O_5 + 48 lb. K_2O per acre.

$$N : P_2O_5 : K_2O :: 2 : 5 : 2$$

There were thus 32 treatment combinations with three absolute replicates. The total number of plots under experiment was 96, each of 1/20 acre at sowing, intercepted by buffer strips (4 ft. wide) as a provision against seepage effects.

Sowings were done from 18 to 22 May. Other cultural details were in conformity with the standard agricultural practices prevalent at the Lyallpur Farm.

Farmyard manure, superphosphate and potash were applied before the sowing irrigation. Ammonium sulphate at 100 lb. per acre was also given before sowing. The complementary dose of this fertilizer at 133 lb. per acre was given on 9-10 August.

Collection of data

Fortnightly height measurements and nodal counts of the main axis were taken on five plants in each plot. Cotyledonary node was reckoned as the zero node for counts and served as the lower fixed point for height. The point of attachment to main axis of the last leaf unfolded marked the upper point. The records for height and nodes

allowed of the calculation of the average internodal length.

Twenty plants, to form two units of ten plants each, were tagged in each subplot for determinations of the number of bolls and the weight of *kapas* per boll prior to each picking. These characters are the components of yield. The yield of *kapas* from each experimental plot, 1/48 acre each after rejecting non-experimental borders, was recorded for each picking. The cotton sticks from the experimental beds were weighed at harvest.

Experimental results

Height, node number and internodal length. The data for height, node number and internodal length have been graphically represented in Fig. 1. As potash had no effect on any of these characters the generalized values of o, n, p and np alone have been depicted.

The performance of the four groups of treatments, averaged over both levels of organic manure and potash is shown in Figs. 1A and 1B, under w_1 and w_2 separately. The salient features of these curves are summarized below.

The curves for height swing into characteristic S-shape. They rise slowly at first, followed by a rapid increase in elongation up till the 5th stage when a gradual deceleration sets in. The curves run together in the initial stages and widen with time. The ultimate trends are not discernible till the 4th stage is reached. Finally, they fall in the order $np > n > p > o$ under either type of waterings, but the differences are of a much higher order under heavy waterings. This indicates interaction of watering with nitrogen. The general level of curves for w_2 is higher than that for w_1. The effect of nitrogen and phosphorus are additive under w_1 as well as w_2. Thus there is little evidence of interaction of N with P or of watering with N×P.

The curves for node number rise rapidly to start with, sharply deflecting at the 3rd stage. The decelerated rate is, however, maintained over a long period. Curves tend to be parabolic in form with concavity towards the axis of abscissa. There are little differences in number of nodes due to manures at any stage in w_1. There is an indication of an appreciable increase under w_2.

The internodal length reveals a steep rise up to the 4th stage after which extension growth slows down rather rapidly with time. Node production, on the other hand, is kept up to a fairly later stage. In fact, there is a tendency for a fall in the internodal length towards maturity. This is due to continued meristematic activity of plants, though at a much slower rate, in the later stages. The curves for height take a resultant course.

The effect of nitrogen on the internodal length is specially marked with w_2 and starts quite early. The differences magnify with time. The effect of phosphorus (in the absence of nitrogen) is scarcely visible under w_1, and is of a much lower order, as compared with the effect of nitrogen, under w_2 as well. The influence on the elongation of internodes is maximum in case of np, with either type of watering.

The data rearranged for o, n, p, and np in the absence and in the presence of organic manure are plotted for the same characters in Figs. 1C and 1D respectively. The effect of p on height in absence of organic manure (Fig. 1c) is as marked as that of n while np causes but little further improvement. In the presence of organic manure (Fig. 1D) n continues to increase the height while p apparently depresses it. Furthermore, there is an indication of a continued increase due to np over that of n alone. In the presence of organic manure, therefore, any apparent increase due to phosphorus in the presence of nitrogen (np-n) is counterbalanced by a corresponding decrease due to phosphorus in the absence of nitrogen (p-o). On the other hand, there is a definite increase, as already mentioned, by phosphorus in the absence of organic manure. This brings out clearly the interaction M×P, but the differential behaviour of this interaction with nitrogen depicts N×M×P also. There is evidence of a real and marked effect due to phosphorus in the absence of both organic manure and nitrogen.

The above effects are not shown so well on node-number but are again conspicuous on the internodal length. This means that the treatment differences in height are mostly contributed by effects on the internodal length.

Boll number, boll weight and yield. The records for yield characters, collected plot by plot during the picking season, were properly compiled and statistically analysed (Table I). The mean squares for the different components, with the ratios they bear to the error variance are stated for the significant or the suggestive effects only.

The magnitude and the direction of effects are shown in the summary tables (II—V) showing all the main effects and their significant interactions, with appropriate standard errors.

A study of Table II reveals that watering has improved the size of bolls but not their number. The magnitude of increase is also the greatest of all the factors, though it is also subject to larger errors. Limitation of the design, however, is responsible for the non-significance of the effects of water on yield. For the same reason, the average influence of organic manure is not demonstrable on any of the characters in this experiment. Nitrogen is the most potent factor in-as-much as improvement is twofold. The response is well pronounced on both the number and the size of bolls and collective effect appears on yield.

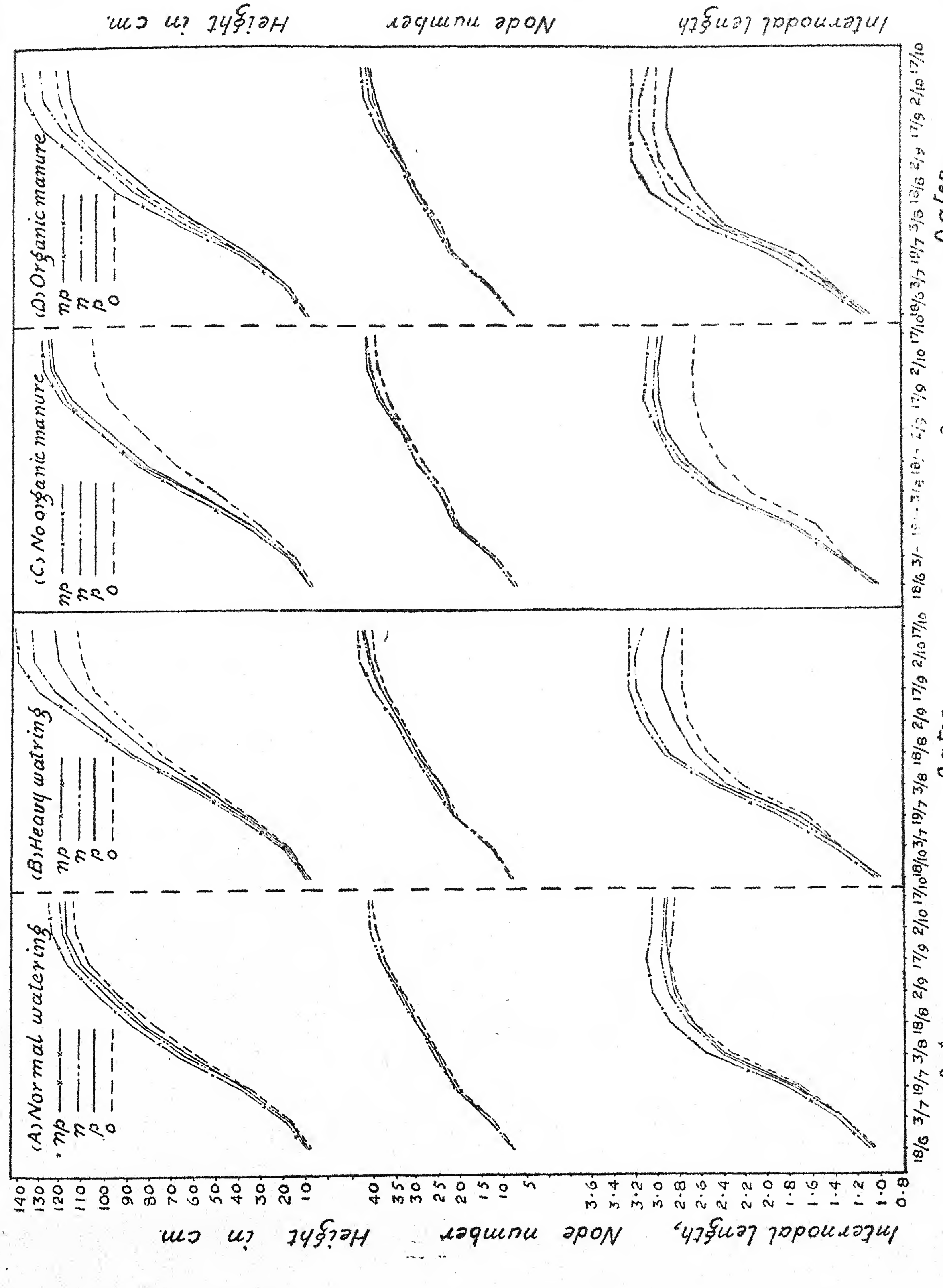

Fig. 1. Treatment effects on height, node number and internodal length

TABLE I

Analysis of variance

Experiment I

Due to	D. F.	Boll number: Mean square	Boll number: F	Boll weight: Mean square	Boll weight: F	Yield of *kapas*: Mean square	Yield of *kapas*: F
Blocks	2	144,968		0·0096		24,701·23	
W	1	48,801		1·6744	6·52*	13,585·04	
M	1	60,741		0·0478		6,080·17	
W × M	1	38,960		0·0171		888·17	
Error (a)	6	25,891		0·2569		10,333·0624	
Main plots	11						
N	1	171,781	13·04**	0·3545	10·97**	207,762·05	39·53**
P	1	10,576		0·1088	3·37	20,358·38	3·87
K	1	47,408	3·60	0·0110		51·04	
N × P	1	2,969		0·0006		2,420·04	
N × K	1	2,574		0·0732		77·04	
P × K	1	17,614		0·0019		1,457·04	
W × N	1	28,300	2·15	0·2516	7·78**	97,920·38	18·63**
W × P	1	7,093		0·0028		975·38	
W × K	1	3,597		0·0649		1,335·04	
M × N	1	12,789		0·1013		1,472·67	
M × P	1	54,506	4·14*	0·1088	3·37	35,882·67	6·83*
M × K	1	571		0·2707	8·38**	73·50	
N × P × K	1	2,235		0·0923		376·04	
W × N × P	1	29,975		0·0084		5,859·38	
W × N × K	1	6,568		0·0215		1,962·04	
W × P × K	1	1,722		0·0095		570·38	
M × N × P	1	1,307		0·3080	9·53**	45,414·00	8·64*
M × N × K	1	24,639		0·0447		16,120·17	
M × P × K	1	23,342		0·0564		12,060·17	
W × M × N	1	7,240		0·0210		16,432·67	
W × M × P	1	6,019		0·0259		2,688·17	
W × M × K	1	5,229		0·0504		32·67	
3rd & 4th order interactions	6	7,972		0·0678		3,165·39	
Error (b)	56	13,167·52		0·032321		5,255·3303	
Between plots	95						

* Significant at 5 per cent level ** Significant at 1 per cent level

TABLE II

Main effects

—		Number of bolls per plant: Actual	Number of bolls per plant: Difference	Number of bolls per plant: ± S. E.	Weight of seed cotton per boll in gm.: Actual	Weight of seed cotton per boll in gm.: Difference	Weight of seed cotton per boll in gm.: ± S. E.	Yield of *kapas* in md. per acre: Actual	Yield of *kapas* in md. per acre: Difference	Yield of *kapas* in md. per acre: ± S. E.
Watering	w_1	51·22	—3·19	±2·32	2·091	+0·186*	±0·073	20·55	+0·89	±0·778
	w_2	48·03			2·277			21·44		
Organic manure	*o*	47·85	+3·55	±2·32	2·200	—0·032	±0·073	20·70	+0·60	±0·778
	m	51·40			2·168			21·30		
Nitrogen	*o*	46·63	+5·98**	±1·66	2·141	+0·086**	±0·026	19·25	+3·49**	±0·555
	n	52·61			2·227			22·74		
Phosphorus	*o*	48·88	+1·49	±1·66	2·161	+0·046	±0·026	20·45	+1·09	±0·555
	p	50·37			2·207			21·54		
Potash	*o*	51·20	—3·15	±1·66	2·176	+0·016	±0·026	20·97	+0·06	±0·555
	k	48·05			2·192			21·03		

Next in importance is phospohrus, with low suggestive response, i.e. 1·09 md. per acre as compared with 3·49 for nitrogen. It appears phosphorus has operated through increase in boll size. This confirms results obtained by Crowther [1937]. Except for a suggestive decline in boll number, there is little effect of potash application.

TABLE III

Watering × nitrogen interactions

Boll number per plant			Boll weight (gm.)			Yield of *kapas* (md. per acre)		
	w_1	w_2		w_1	w_2		w_1	w_2
o	49·44	43·83	*o*	2·084	2·198	*o*	20·00	18·50
n	*53·00*	*52·24*	*n*	*2·097*	*2·356*	*n*	*21·09*	*24·39*
Diff. ±2·34 . .	*+3·56*	*+8·41***	Diff. ±0·037 . .	*+0·013*	*+0·158***	Diff. ±0·785 . .	*+1·09*	*+5·89***
W × N . . .	2·43	±1·66	W × N	0·072**	±0·026	W × N	2·40**	±0·555

Interactions. The interrelation of watering and nitrogen is shown in Table III. There is distinct evidence that water enhances the utilization of nitrogen. The increase in boll weight due to nitrogen is highly significant under heavy irrigations while there is little effect with ordinary waterings. The effect on boll number also points to the same direction though the interaction value fails to attain significance. It thus appears at its best in yield. Only 1·09 md. per acre increase in yield by nitrogen is recorded under ordinary waterings and this is apparently caused by its beneficial effect on bearing alone. The effectiveness of nitrogen increases by simultaneous increase in water-supply and has expressed itself in raising the yield by 5·89 md. per acre through its influence on both the boll number and the boll weight. This interaction has materially contributed to the significance of the main effects of nitrogen and water. Omission of any one of the factors in this experiment would have lowered the magnitude of the response to the other.

The effect of phosphorus in the presence and the absence of organic manure is shown in Table IV. There is an appreciable increase in the boll number by phosphorus in the absence of organic manure and a slight decrease in its presence. This differential behaviour is responsible for the significant interaction of P with M.

Mention has already been made of the beneficial effect of phosphorus on boll size. On further analysis of the data, it is seen that this improvement is peculiar to phosphorus in the absence of the organic manure. The nature of the interaction on boll number and boll weight is, therefore, similar.

TABLES IV & V

Interaction effects of organic manure, phosphorus and nitrogen

TABLE IV

M × P interaction

Boll number per plant	*o*	*m*
o	45·42	52·34
p	*50·27*	*50·46*
Diff. ± 2·34 .	*+4·85**	*—1·88*
Interaction value	—3·36*	±1·66
***Boll weight* (gm.)**	*o*	*m*
o	2·152	2·168
p	*2·247*	*2·168*
Diff. ± 0·037 .	*+0·095**	. .
Interaction value	—0·047	±0·026
Yield of* kapas *(md. per acre)	*o*	*m*
. . . .	19·42	21·48
p	*21·97*	*21·11*
Diff. ±0·785 .	*+2·55***	*—0·37*
Interaction value	—1·46*	±0·555

TABLE V

M × N × P interaction

Boll number per plant	*o*	*n*	*m*	*mn*
o	42·59	48·25	48·41	56·28
p	*48·75*	*51·80*	*46·79*	*54·14*
Diff. ± 3·31 .	*+6·16*	*+3·55*	*—1·62*	*—2·14*
Interaction value	0·52	±1·66		
***Boll weight* (gm.)**	*o*	*n*	*m*	*mn*
o	2·048	2·256	2·190	2·146
p	*2·219*	*2·275*	*2·106*	*2·230*
Diff. ±0·052 .	*+0·171***	*+0·019*	*—0·084*	*+0·084*
Interaction value.	0·080**	±0·026		
Yield of* kapas *(md. per acre)	*o*	*n*	*m*	*mn*
o	16·53	22·32	20·51	22·45
p	*21·08*	*22·86*	*18·89*	*23·34*
Diff. ±1·11 .	*+4·55***	*+0·54*	*—1·62*	*+0·89*
Interaction value :	1·63**	±0·555		

The interaction M×P is even more glaring in case of yield. The effect of phosphorus is significant at 1 per cent level in the absence of organic manure, there being no effect in its presence.

The significance of M×N×P interaction necessitates the study of the effect of phosphorus under *o, n, m,* and *mn,* individually. These relations have been shown for the three characters in Table V. The effect of phosphorus on boll number is not significant under any of the four combinations of nitrogen and organic manure and M×N×P is insignificant. The effects on boll weight and yield are different. A significant increase due to phosphorus is conditioned by the absence of both organic manure and nitrogenous fertilizers.

Stem dry matter. Essentially the same relations as for height and yield were found to hold in case of stem dry matter.

Experiment II (1938-39)

In view of the results obtained during 1937-38, it was next necessary to repeat the experiment under similar conditions of soil but under intensive system of cropping. A piece of four acres was selected in the same square, under the rotation wheat—*toria*—cotton.

Description of the experiment

This experiment was similar to the one already described with minor changes. Organic manuring was omitted as a treatment. Early and late applications of nitrogen were included as separate factors. The treatments were all combinations of :—

	(o) (n_l)	×	(o) (n_e)	×	(o) (p)	×	(o) (k)	×	(w_1) (w_2)
Doses	N at 50 lb. per acre given on 16-17 August		N at 50 lb. per acre		P_2O_5 at 100 lb. per acre		K_2O at 200 lb. per acre		Water (normal and heavy) as in Expt. I

Applied on 18-20 May before sowing

Nitrogen, phosphoric acid and potash were supplied in the same forms as in the first experiment.

The purpose of the experiment was to obtain equally precise information on all the important comparisons. It was also necessary to reduce the block size to increase precision by confounding. Therefore, an 8×8 quasi-Latin square was adopted to enable the elimination of two-way systematic soil variations. The layout plan of the experiment is set out in Fig. 2.

There were 64 plots of 1/21·8 acre each (33 ft. ×60½ ft.), separated by interstrips, 7 ft. wide. Sowings were done from 22 to 26 May.

FIG. 2

8×8 Quasi-Latin square

2^2 Factorial Design on 4-F Cotton (Year 1938-39)

(Plan and yields in chhataks)

Confounded completely among rows $N_E \times P \times K$, $N_L \times K \times W$, $N_E \times N_L \times P \times W$

Rows	1	2	3	4	5	6	7	8
1	w_2 127	$nekw_1$ 164	$nlpkw_2$ 189	pkw_1 105	$nenlkw_2$ 278	$nenlpw_1$ 171	$nepw_2$ 110	nlw_1 203
2	$nlkw_1$ 257	$nenlpkw_1$ 256	pw_1 148	$nlpw_2$ 271	new_1 205	$nepkw_2$ 158	$nenl\ w_2$ 206	kw_2 125
3	pkw_1 152	$nepw_2$ 248	$nl\ w_1$ 219	w_2 150	$nenl\ pw_1$ 216	$nenl\ kw_2$ 214	$nekw_1$ 206	$nl\ pkw_2$ 272
4	$nenl\ pkw_2$ 335	$nl\ kw_2$ 272	$nepkw_1$ 222	$nenl\ w_1$ 311	kw_1 122	pw_2 139	$nl\ pw_1$ 219	new_2 290
5	$nepw_1$ 223	pkw_2 142	$nenl\ kw_1$ 299	$nekw_2$ 236	$nlpkw_1$ 254	$nl\ w_2$ 254	w_1 133	$nenl\ pw_2$ 301
6	$nl\ pw_2$ 240	$nenl\ w_2$ 303	kw_2 141	$nlkw_1$ 242	$nepkw_2$ 258	new_1 190	$nenl\ pkw_1$ 286	pw_1 117
7	$nekw_2$ 276	w_1 131	$nenl\ pw_2$ 317	$nepw_1$ 261	$nl\ w_2$ 234	$nl\ pkw_1$ 156	pkw_2 166	$nenl\ kw_1$ 319
8	$nenl\ w_1$ 276	$nl\ pw_1$ 234	new_2 248	$nenl\ pkw_2$ 319	pw_2 173	kw_1 123	$nl\ kw_2$ 258	$nepkw_1$ 282
Columns	1	2	3	4	5	6	7	8

$N_E \times K \times W$, $N_L \times P \times W$ and $N_E \times N_L \times P \times K$ confounded completely among columns

Collection of data

There were 11 rows in each plot, out of which two at the borders were rejected as non-experimental. Of the nine inner rows, four were set apart for dry weight and flowering data, and the remaining five reserved for yield and observational records, viz. height and nodes, boll number and boll weight.

Except yield results which were based on the entire experimental areas of each plot(15 ft. × 48·4 ft. = 1/80 acre), the other data relate to observations taken on selected plants randomly distributed in each plot. The necessary particulars are given in Table VI.

TABLE VI

Type of observation	Interval between two stages	Date of first observation	Date of final observation	Size of sample	Remarks
Height and nodes . . .	14 days	27-28/6	31/10, 1/11	10 plants	Each spaced 3 ft. × 1½ ft.
Fresh and dry weights of different parts except roots	14 days	29/6-2/7	19-22/10	5 ,,	First two samples before thinning comprised 30, 15 plants respectively.
Flower counts	Daily	1/9	30/10	6 ,,	Set bolls counted finally on these plants
Boll number and boll weight before each picking					*Kapas* samples ginned

These records enabled the computation of a good deal of derived data, e.g. internodal length, growth rates, distribution of dry matter in parts, setting percentage, ginning out-turn, etc.

Experimental results

The entire data collected and derived were analyzed statistically. The 'analysis of variances' for the values at the final stage in case of most of the characters are presented in Tables VII and VIII which form the basis for the reduction of data in the form of summary tables. Effects of N and water alone are discussed in the following pages. P and K and their interactions are ineffective and will not receive attention.

TABLE VII

Analyses of variances

Experiment II

Due to	D. F.	Height: Mean square	Height: F	Node number: Mean square	Node number: F	Internodal length: Mean square	Internodal length: F	Flower production: Mean square	Flower production: F
Rows	7	303·32	3·25*	1·4146	1·03	0·2391	5·39**	22358	2·21
Columns	7	172·464	1·809	2·4375	1·78	0·0807	1·82	10437	1·03
Treatments	25	390·301	4·09**	8·8315	6·476**	0·0952	2·15*	57222	5·66**
W	1	2149·481	22·55**	17·2225	12·63**	0·7098	16·02**	7331	...
N_L	1	2012·644	21·11**	87·8900	64·45**	0·1936	4·37*	376229	37·25**
N_E	1	4403·981	46·34**	87·4225	64·10**	0·9900	22·35**	745416	73·81**
P	1	3·195	...	0·9025	...	0·0012	...	4675	...
K	1	41·441	...	1·3225	...	0·0060	...	47	...
W × N_L	1	8·925	...	0·1406	...	0·0072	...	468	...
W × N_E	1	92·881	...	0·0400	...	0·0506	...	5421	...
W × P	1	11·475	...	0·3600	...	0·0156	...	5384	...
W × K	1	72·462	...	...	...	0·0452	...	4241	...
N_L × N_E	1	313·732	3·29	12·7806	9·37**	0·0541	...	149479	14·80**
N_L × P	1	14·726	...	0·0056	...	0·0086	...	1492	...
N_L × K	1	72·462	...	4·9506	...	0·0016	...	17922	...
N_E × P	1	57·191	...	0·0100	...	0·0281	...	3408	...
N_E × K	1	0·375	...	1·0000	...	0·0030	...	10328	...
P × K	1	17·956	...	0·4225	...	0·0196	...	5987	...
High order interactions . .	10	48·461	...	0·6317	...	0·0245	...	9271	...
Error	24	95·309	...	1·3637	...	0·0443	...	10099	...

TABLE VIII

Analysis of variances

Experiment II

Due to	D. F.	Setting per cent.		Boll number		Boll weight		Yield of *kapas*	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Rows	7	61·80	5·35**	313·24	...	1·4267	16·80**	4576·57	4·72**
Columns	7	12·05	1·04	184·12	...	0·4292	5·05**	3790·79	3·91**
Treatments	25	14·92	1·29	1489·01	4·37**	0·4214	4·96**	6986·81	7·21**
W	1	12·60	...	299·51	...	2·1481	25·30**	4692·25	4·84*
N_L	1	35·70	3·09	19896·87	58·41**	3·3512	39·47**	90751·56	93·71**
N_E	1	90·25	7·81**	11871·46	34·85**	2·0075	23·65**	63504·00	65·57**
P	1	8·70	...	409·81	...	0·2156	...	81·00	...
K	1	35·40	3·06	2·91	...	0·0048	...	729·00	...
W × N_L	1	28·36	2·45	1·39	...	0·0142	...	315·06	...
W × N_E	1	1·44	...	298·21	...	0·5710	6·72*	256·00	...
W × P	1	6·25	...	42·66	...	0·0023	...	240·25	...
W × K	1	0·42	...	674·38	...	0·0099	...	400·00	...
N_L × N_E	1	55·88	4·84*	566·74	...	0·7799	9·18**	8789·06	9·07**
N_L × P	1	15·02	...	72·14	...	0·0686	...	333·06	...
N_L × K	1	2·03	...	167·86	...	0·0326	...	945·56	...
N_E × P	1	0·56	...	981·65	...	0·2019	...	30·25	...
N_E × K	1	10·89	...	0·01	...	0·1028	...	961·00	...
P × K	1	13·32	...	1001·33	...	0·1565	...	196·00	...
High order interactions . .	10	5·616	...	79·13	...	0·08682	...	244·62	...
Error	24	11·55	...	340·61	...	0·0849	...	968·43	...

Height, node number and internodal length. The results of the effects of treatments on these characters are arranged in Table IX. Nitrogen applied either before sowing or before flowering has significantly increased the height, node number and the internodal length of the main axis. The magnitude of increase in the final height is higher with the early application of nitrogen as compared with the later. This is to be attributed to greater elongation of the internodes under the early application. Either of the applications are equally effective for node development.

TABLE IX

Treatment effects on height, node number and the internodal length

(Mean height in cm. per plant)

Nitrogen, early and late

	o	n_l	Diff.
			±3·45
o . . .	100·4	116·0	±15·64**
n_e . . .	*121·4*	*128·2*	*+6·79*
Diff. ±3·45	+21·0**	+12·2**	—8·85/2

Interaction ±2·44 = —4·425

Nitrogen and watering

	o	n_e	n_l	n_e+n_l	Mean
w_1 . . .	97·7	113·4	109·6	122·3	110·7
w_2 . . .	*103·1*	*129·5*	*122·5*	*134·1*	*122·3*
Diff. . . .	+5·4	+16·1**	+12·9**	+11·8*	+11·6**
S. Ed.	$\underbrace{\qquad\qquad}_{\pm 4\cdot 48}$				±2·44

TABLE IX—*contd.*

Average number of nodes on the main axis

	o	n_l	Diff.		o	n_e	n	n_e+n_l	Mean
			±0·413						
o . .	36·9	40·1	+3·24**	w_1 . .	36·4	39·5	39·6	41·2	39·2
n_e . .	*40·1*	*41·6*	*+1·45***	w_2 . .	*37·4*	*40·7*	*40·7*	*42·0*	*40·2*
Diff. ±0·413	+3·2**	+1·45**	—1·79/2	Diff. . .	+1·0	+1·2	+1·1	+0·8	+1·0**
Interaction ±0·292= —0·895**				S. Ed. .		±0·584			±0·292

Mean internodal length (cm.)

	o	n_l	Diff.		o	n_e	n_l	n_e+n_l	Mean
			±0·074						
o . .	2·71	2·89	+0·18*	w_1 . .	2·68	2·87	2·77	2·97	2·82
n_e . .	*3·02*	*3·08*	*+0·06*	w_2 . .	*2·75*	*3·18*	*3·01*	*3·19*	*3·03*
Diff. ±0·074	+0·31**	+0·19*	—0·12/2	Diff. . .	+0·07	+0·31**	+0·24*	+0·22*	+0·21**
Interaction ±0·053= —0·06				S. Ed. . .		±0·106			±0·053

A further increase in height has occurred when nitrogen applied before sowing is supplemented by an equivalent amount of later dressing. There is, however, a clear evidence of falling off in the effectiveness of the additional dose. The interaction $N_E \times N_L$ is on the verge of significance. This is in conformity with the law of diminishing utility. The interaction $N_E \times N_L$ is highly significant in case of node number but it is not so in the case of the internodal length.

Watering has an increasing effect in case of all the three characters at all levels of nitrogen. Therefore the mean response to watering is statistically significant. The effect of watering is to be attributed to an increase in the internodal length mainly, the effect on node number being much smaller.

It is noteworthy that both nitrogen and water stimulate elongation of the main axis, but the magnitude of increase is higher under nitrogen than under heavy watering. The effect of the former is relatively better marked on node production than on the internodal length. The converse is true of the effect of water. Moreover, the effect of water tends to vary with nitrogen. In the absence of nitrogen the increase due to water does not attain significance anywhere. In the presence of nitrogen greater response to water is evidenced in longer internodes and taller plants. There is not the slightest indication of the interaction of nitrogen with water in case of node number. Nitrogen does not depend for node production on water which, in turn, is more important for the enlargement phase of growth. Similar results were obtained by Crowther [1934] with the difference that interaction effects were more pronounced in his case. That can be attributed, at least in part, to the inclusion of a third level of light watering as a treatment in his experiment.

Maximum dry weight per plant. A study of Table X reveals that nitrogen has significantly increased the dry weight (dead leaves excluded). The increase is relatively greater with the early application than with the later. The early application has the advantage of time for making extra growth. The increase due to double dose (n_e+n_l) is maximum though it is not proportionate to the amount added.

The effect of heavy watering is also significant but the effect is much smaller in magnitude as compared with that of nitrogen. The main effect of water derives its significance from the appreciable increases by double watering in the presence of nitrogen, especially the early applications. The interaction (water × nitrogen) is, therefore, better marked here than in the case of height.

TABLE X

Treatment effects on maximum dry weight in gm. per plant

Nitrogen, early and late

	o	n_l	Diff.
			±21
o	312·0	412·5	+100·5**
n_e	446·6	465·9	+19·3
Diff. ±21	+134·6**	+53·4*	—81·2/2

Interaction ±14·8= —40·6*

Nitrogen and water

	o	n_e	n_l	n_e+n_l	Mean
w_1	312·5	415·3	402·6	433·0	390·8
w_2	311·6	478·0	422·4	498·9	427·7
Diff.	—0·9	+62·7*	+19·8	65·9*	+36·9*
S. Ed.	±29·6				±14·8

TABLE XI

Treatment effects on the total number of flowers produced per plant

Nitrogen, early and late

	o	n_l	Diff.
			±5·92
o	97·8	139·5	+41·7**
n_e	149·8	159·3	+9·5
Diff. ±5·92	+52·0**	+19·8**	—32·2/2

Interaction ±4·2 = —16·1**

Nitrogen and water

	o	n_e	n_l	n_e+n_l	Mean
w_1	97·5	147·5	139·3	155·0	134·8
w_2	98·1	152·1	139·6	163·6	138·3
Diff.	+0·6	+4·6	+0·3	+8·6	+3·5
S. Ed.	±8·37				±4·19

Flower production. Nitrogen whether applied early or late has increased the aggregate number of flowers (Table XI). The effect is similar to that on dry weight and final height. Further increase in flowering is caused when the early application is augmented by a late one but this increase is rather low. Watering alone or in combination with nitrogen has not influenced flower production.

TABLE XII

Treatment effects on setting percentage

Nitrogen, early and late

	o	n_l	Diff.
			±1·201
o	31·7	31·3	—0·4
n_e	32·2	35·5	+3·3**
Diff. ±1·201	+0·5	+4·2**	+3·7/2

Interaction ±0·849 = 1·85*

Nitrogen and water

	o	n_e	n_l	n_e+n_l	Mean
w_1	30·7	31·0	31·2	36·2	32·3
w_2	32·7	33·4	31·5	34·9	33·1
Diff.	+2·0	+2·4	+0·3	—1·3	+0·8
S. Ed.	±1·698				±0·849

Setting percentage. Setting percentage is affected differently by nitrogen (Table XII). Neither the early application by itself encourages the percentage success of flowers into bolls nor does the late one alone. The reaction to the combined dose is strikingly favourable. Thus the interaction between the two times of application is positive and significant. It seems, then, that not until the concentration of nitrogen within the plant is very high, is the setting percentage affected.

Boll number, boll weight and yield. A study of Table XIII reveals that nitrogen whether applied early or late stimulates reproductive development. The latter appears to be more effective than the former. The double dressing has exactly doubled the out-turn as compared with the control, but its efficiency per unit of nitrogen supplied is lower. Every lb. of nitrogen gives a return of 13·28, 15·17 and 10·63 lb. of *kapas* in case of the early, the late and the combined applications, respectively. The superiority of the late application in yield is in accord with previous experience in the Punjab, but the difference is not statistically significant. The interaction between the two times of application is of the type recorded for the vegetative characters.

Mention has already been made of the operation of $N_E \times N_L$ interaction in the other direction in case of setting percentage. This counteracts the negative significant interaction in flower production with the result that interaction effect is absent in boll number. On the other hand, the improvement in boll size is seen to decline with the addition of the supplementary dose, and thus negative $N_E \times N_L$ interactions reappears in yield.

The mean response to water on yield appears to be just a reflection of its significant effect on boll weight, since boll number is not influenced by this factor. Improvement in the quality of opening and yield due to water is relatively smaller in magnitude.

TABLE XIII

Treatment effects on boll number, boll weight and yield

Nitrogen, early and late				*Water and nitrogen*					
	o	n_l	Diff.		o	n_e	n_l	n_e+n_l	Mean
(Boll number per square yard)									
			±3·26						
o . .	51·87	72·48	+20·61**	w_1 . .	51·37	66·66	72·97	80·61	67·90
n_e . .	*68·46*	*83·12*	*+14·66***	w_2 . .	*52·37*	*70·27*	*71·98*	*85·63*	*70·06*
Diff. ±3·26	+16·59**	+10·64**	−5·95/2	Diff. . .	+1·00	+3·61	−0·99	+5·02	+2·16
Interaction ±2·307 = −2·97				S. Ed. .	±4·61				±2·307
Weight of kapas *per boll*									
			±0·052						
o . .	1·781	2·120	+0·339**	w_1 . .	1·632	2·020	1·992	2·147	1·948
n_e . .	*2·069*	*2·187*	*+0·118**	w_2 . .	*1·931*	*2·117*	*2·249*	*2·227*	*2·131*
Diff. ±0·052	+0·288**	+0·067	−0·221/2	Diff. . .	+0·299**	+0·097	+0·257**	+0·080	+0·183**
Interaction ±0·036 = −0·110**				S. Ed. . .	±0·073				±0·036
			±1·031						
o . .	12·86	22·11	+9·25**	w_1 . .	12·08	20·54	20·90	25·01	19·63
n_e . .	*20·96*	*25·82*	*+4·86***	w_2 . .	*13·63*	*21·37*	*23·32*	*26·63*	*21·24*
Diff. ±1·031	+8·10**	+3·71**	−4·39/2	Diff. . .	+1·55	+0·83	+2·42	+1·62	+1·61*
Interaction ±0·729 = −2·19**				S. Ed. . .	±1·459				±0·729

One point is note-worthy in connection with the interrelation of water and nitrogen on boll weight and yield.

There is little evidence that heavy watering enhances the utilization of nitrogen even when applied late (effect of water under *o* with *nl*). This result is at variance with the one emanating from the previous experiment. Experiment I was conducted on a piece of land that lay fallow for full one year, during which period it received lot of preparatory tillage. Fresh applications of the nitrogenous fertilizer only augmented the recuperated natural resources. Thus, nitrogen depended, for its full effect, on water which acted as a limiting factor.

In the second experiment, the primary requirement was nitrogen as the cotton crop followed *toria* and *sarson* (*Brassica* sp.) which left little time for preliminary cultivation. The level of fertility was, therefore, low, due to greater intensity of cropping and the response to nitrogen was high and there was no further increase in yield by extra watering.

The percentage increases due to nitrogen and water over the basal treatments (control for nitrogen treatments and normal waterings for water effect) are given in Table XIV (*a*) for boll number, boll weight and the resulting yield, individually.

TABLE XIV

The relative contribution of boll weight and boll number to total increase in yield

	(*a*) *Percentage increases over basal treatment*				(*b*) *Percentage distribution of increase in* kapas *into components of yield*			
	Nitrogen			Water	Nitrogen			Water
	N_E	N_L	N_E+N_L	W_2	N_E	N_L	N_E+N_L	W_2
Boll number . . .	32·0	39·7	60·2	3·2	66·4	67·6	72·5	25·4
Boll weight . . .	*16·2*	*19·0*	*22·8*	*9·4*	*33·6*	*32·4*	*27·5*	*74·6*
Total .	48·2	58·7	83·0	12·6	100	100	100	100

These have been derived from the data presented in Table XIV and give a quantitative idea of the relative share of the two components in the total contribution to yield. It is seen that although nitrogen causes a substantial increase in boll size, it is relatively more important for bearing. Water mainly functions through improvement in boll weight though nitrogen is far superior to it quantitatively, in this respect even. The specific functions of water and nitrogen are further illustrated in Table XIV (*b*). The relative importance of single dose of nitrogen for bearing is double that for the quality of bolls, and it is still higher in the case of the double dose. As regards water, the position is reverse.

Ginning percentage. Summarized results of the effect of nitrogen and water on the proportion of lint to *kapas* are presented in Table XV. Nitrogen has significantly lowered the ginning percentage. The improvement in boll size through N is not shared equally by seed and lint. Seed weight seems to derive benefit rather than the

TABLE XV

Treatment effects on ginning percentage

	o	*nl*	Diff. ±0·389
o . . .	33·89	31·89	—2·00**
n . . .	*32·09*	*31·01*	*—1·08**
Diff: ±0·389	—1·80**	—0·88*	+0·92/2
Interaction ±0·275 =	+0·46		

	o	n_e	n_l	n_e+n_l	Mean
w_1 . .	34·17	31·86	31·97	31·06	32·26
w_2 . .	*33·62*	*31·91*	*32·21*	*30·96*	*32·17*
Diff: . .	—0·55	0·05	0·24	—0·10	—0·09
S. Ed. . .	±0·55				±0·275

lint weight. The depressing effect of nitrogen on ginning outturn appears to be linear within the range of doses used. Water does not influence ginning outturn either singly or in combination with nitrogen.

Correlation studies

The treatment effects on yield and the developmental characters discussed in the preceding pages suggested that various characters were correlated. Correlation coefficients between different pair of characters, were, therefore, worked out for the whole data as well as the different components, viz. rows, columns, treatments and error (Table XVI).

The treatment yields are highly correlated positively with vegetative growth as measured by height and dry weight, and with meristematic activity as given by flower or boll formation. Similarly treatment effects on boll weight are reflected in yield.

TABLE XVI

Correlation coefficients and their significance

—	n	Dry wt. and yield	Height and yield	Boll wt. and yield	Flowers and yield	Bolls and yield	Boll No. and boll wt.	Ginning per cent and boll wt.
Rows	6	0·8875**	0·964**	0·9463**	0·1248	—0·2747	—0·4323	—0·3266
Columns	6	0·8228*	0·8987**	0·9555**	0·3716	0·5481	0·6504	0·1476
† Effective treatments	6	0·9130**	0·8926**	0·9014**	0·954**	0·9807**	0·8252*	—0·8575**
‡ Ineffective treatments	17	0·5784**	0·3815	0·3974	0·4472	0·2528	—0·1146	0·5036*
Error	23	0·4872*	0·8439**	0·5905**	0·4535*	0·4927*	0·1667	0·0492
Total	62	0·8024**	0·8748**	0·8107**	0·7218**	0·7330**	0·3890**	—0·3423**

† Pertaining to nitrogen and water factors, i.e. 8 treatment combinations
‡ Pertaining to phosphorus and potash and all their interactions

The correlations between yield and height, yield and dry weight, and yield and boll weight are also highly significant for the components, rows and columns. These characters are thus reliable criteria of the yield performance on light sandy soils if other conditions, such as variety, spacing and sowing date, are kept similar. But the case is different with the number of flowers or bolls. The rows and columns that are productive in yield are different from those that stimulate flower production or bolling. This is further confirmed by the fact that boll number and boll weight are unrelated so far as components, other than effective treatments, are concerned. Thus flower counts or boll number fairly accurately forestall the yield performance of the treatments but do not serve as reliable guides in forecasting yields from field to field.

The influence of treatments on boll size is negatively correlated with the ginning percentage. Thus improvement in opening caused by a treatment leads to better development of seed.

Very little value can be attached to the significance or otherwise of the correlation coefficients corresponding to the error component, unless these are based on very high number of degrees of freedom, for the sources of variations in these cases are complex and uncontrollable and influence of causal factors cannot be further resolved into components. The same remarks apply to treatments whose effects are insignificant.

PROGRESSIVE GROWTH DATA

The progressive data is illustrated by graphs (Figs. 3, 4 and 5) and dealt with briefly. The effect of N which alone is the most potent factor, is depicted.

Study of Fig. 3 reveals that nitrogen does not increase height appreciably up till 22 August but after this the differences magnify with the advance of time. Deceleration sets in from 5 September, rather rapidly in control, and marks the onset of flowering. Height curve for the plate aplication of nitrogen remains at a uniformly

low level, due to the inclusion of some plants with shorter internodes in such plots, until the addition of nitrogen on 16 August diverts its course. Even though a change in the colour of leaves was observed within 10 days of the late application, it took about three weeks for the plants so treated to get in level with the controls. Thenceforth they gradually gained ascendency over the untreated ones. The supplementary dose begins to stimulate elongation not until five weeks after its addition. As elongation practically ceases after 3 October all over, a falling off in the effectiveness of the supplementary dressing is natural. It may be further noted that the curve for the late application remains at a lower plane throughout and runs parallel to that for the early application. This also proves that even when nitrogen is applied before sowing time it expresses itself in growth from the flowering phase onwards when untreated plots begin to show symptoms of nitrogen starvation.

The response to the single dressing is well marked on node development. The late application is able to catch up the early one. Lower response to the supplementary dressing is again evident.

Essentially the same remarks, as for height, apply to the curves for the internodal length.

Dry matter. The natural logarithms of the total dry weight ($\log_e$ W) for the nitrogen treatments are given in Table XVII to enable the detection of small differences in the early stages. It will be seen on plotting these values that the effect of nitrogen applied early appears on the plants sampled on 11 August and of the late application on 8 September. The differences tend to be cumulative.

Percentage increase in height and dry weight. The differences in height between the successive stages are expressed as percentages of the respective final heights for the treatments, o, n_l, n_e, and n_e+n_l [Fig. 4(*a*)]. The growth rates similarly derived from the dry-weight data are given in the same figure at the top. The dates of irrigation have been shown by arrows.

The curves for height are bimodal in form. The second maximum about 29 August synchronizes with the commencement of flowering. It is also the time when the applications of nitrogen and water begin to show their effect on growth. That is why this maximum is higher in the manured as compared with the control. After the second maximum is attained, the rate of increase all over falls progressively, though the treated plants grow comparatively more vigorously than the untreated ones. In the case of the double application, the rate falls most slowly. The first maximum is the result of the combined effect of the first two irrigations given at short intervals on 5 and 17 July. A study of Table XVIII furnishes evidence in support of this view. The characteristic increase in height during the interval between the secon and the third turn for measurement is correlated with the elongation of the internodal length only. Node number during the same interval shows no corresponding increase. The importance of water for enlargement phase of growth is evident. It must, however, be noted that once the maximum at the fifth interval is obtained, the internodes at the main axis do not

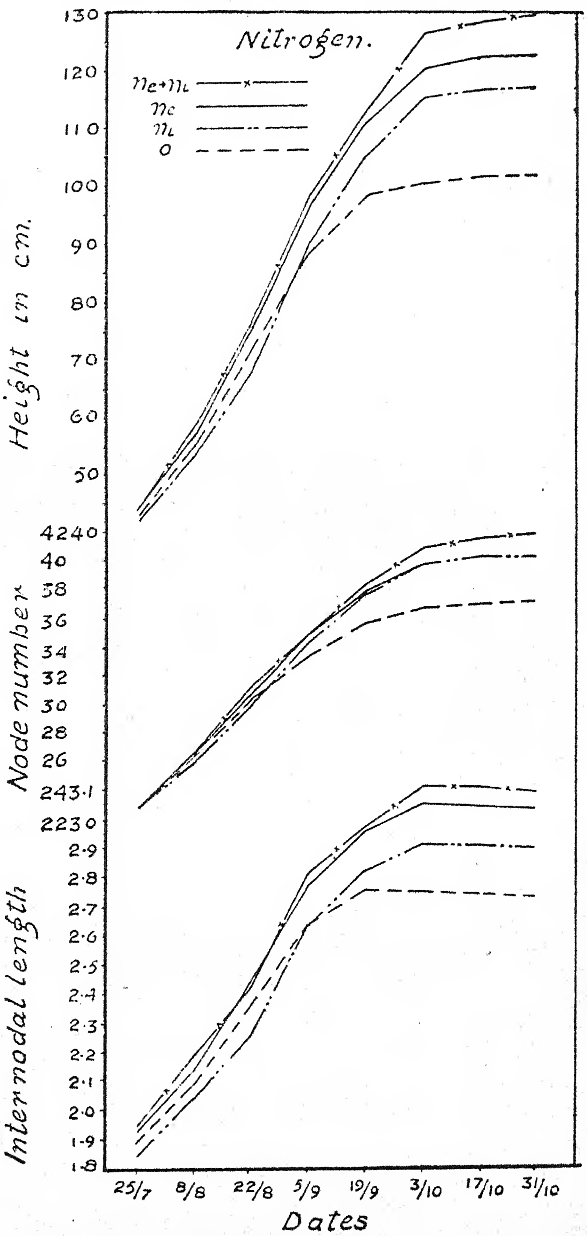

FIG. 3. Effect of nitrogen on height, node number and internodal length

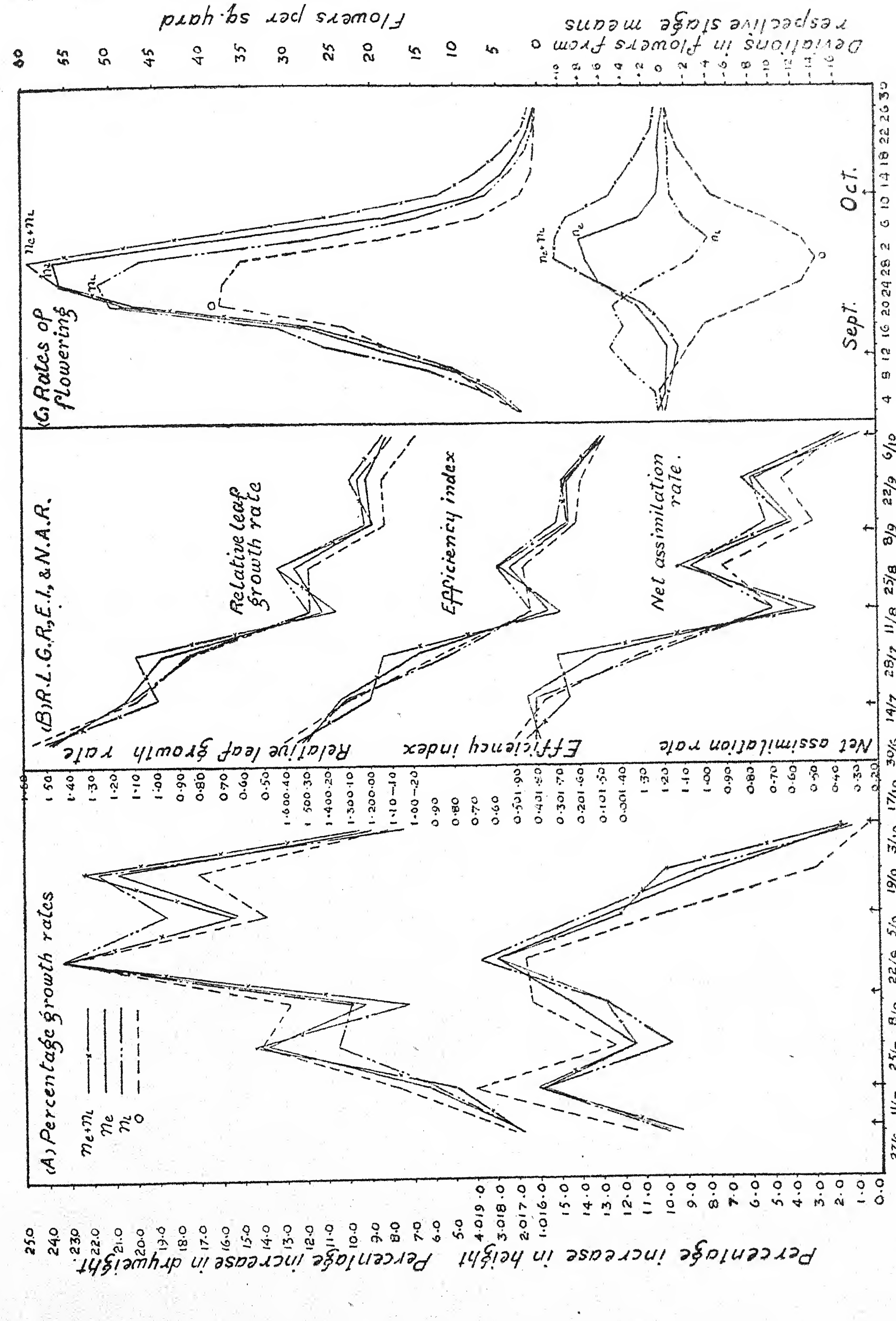

Fig. 4. Effects of nitrogen on rates of growth and flowering

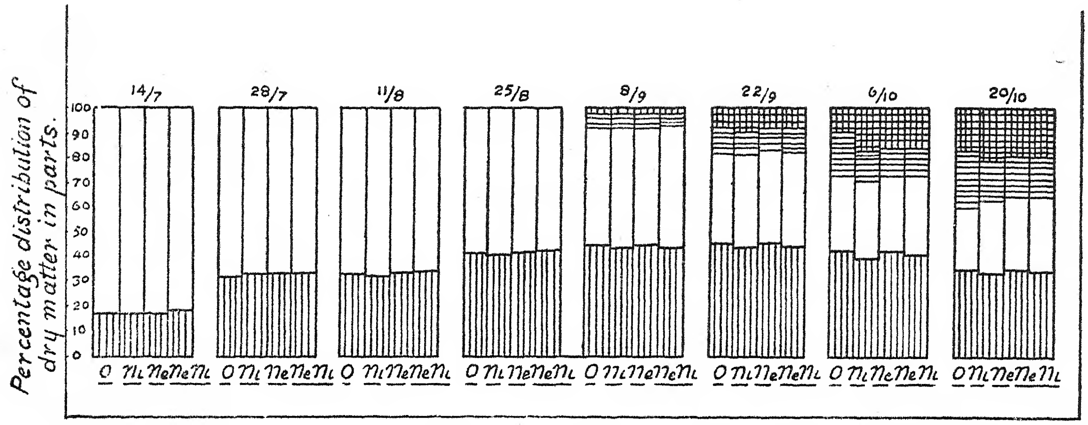

Fig. 5. Effect of nitrogen on the relative distribution of dry matter in parts at different stages
(Portions shaded with vertical lines represent stems; blank space—green leaves; horizontal lines—shed leaves; and squares-bolls)

TABLE XVII

The effect of nitrogen on dry weight (log_e W)

	30/6	14/7	28/7	11/8	25/8	8/9	22/9	6/10	20/10
o	1·38	3·00	4·29	5·17	5·59	6·07	6·28	6·49	6·57
n_l	1·40	2·93	4·26	5·10	5·53	*6·13*	6·44	6·71	6·79
n_e	1·50	3·01	4·36	*5·34*	5·70	6·25	6·50	6·76	6·85
n_e+n_l . . .	1·51	3·07	4·28	*5·40*	5·70	6·28	6·55	6·83	6·93

lengthen at a rapid rate due to pressure of fruiting and, therefore, elongation no longer shows periodicity with the dates of watering.

The curves for percentage increase in dry weight indicate that the maximum output of dry matter, during a unit time interval (a fortnight), that amounts to about 24 per cent of the total dry matter in all the treatments, centres round the 1 September. The diagram possesses a central tendency which synchronizes with the maximum elongation of the main axis and the onset of flowering. Another peak is exhibited by the dry weight curves irrespective of the treatments, about 29 September which marks the time of maximum flowering. This later maximum which is more pronounced in the treated as compared with the untreated plants, is to be attributed to rapid increase in dry matter when the bolls develop. Finally, the rate falls to equally low values in all the series.

TABLE XVIII

Percentage increases in node number and the internodal length

(Untreated plants)

	II-I	III-II	IV-III	V-IV	VI-V	VII-VI	VIII-VII	IX-VIII	X-IX
Node number . .	16·88	14·77	10·05	11·03	8·56	5·88	2·82	0·84	0·27
Internodal length .	10·24	*19·10*	7·33	9·51	10·13	4·45	..	..	..

There is a distinct evidence of prolonged growth activity due to nitrogen. During flowering, the plant grows more vigorously in the presence of nitrogen than in its absence.

Relative leaf growth rate, efficiency index and net assimilation rate

These rates were determined by the following formulae given by Gregory [1926].

Relative leaf growth rate .	$\log_e L_2 - \log_e L_1$
Efficiency index	$\log_e W_2 - \log_e W_1$
Net assimilation rate	$\dfrac{(W_2 - W_1) \times (\log_e L_2 - \log_e L_1)}{L_2 - L_1}$

Where L_1 and L_2 are dry weights of green leaves at the consecutive stages of sampling. W_1 and W_2 denote total dry weights comprised of stems, green and shed leaves, and flower-buds and bolls, at the two stages.

These different rates calculated as above are plotted in Fig. 5 (*b*) for the nitrogen effects.

Relative leaf growth rate in the absence of manuring gives a falling curve, throughout. The rate is maximum to start with, i.e. six weeks after sowing, and drops to zero about 15 September. Early applications of nitrogen appear to have accelerated the rate of leaf growth about the first week of August. The effect of all types of nitrogen treatments, however, is clearly, visible during flowering. The rate for the treated series does not attain negative values, except in the last sample and this, again, is a proof of prolonged vegetative activity with nitrogen applications. Negative values are obtained in the control about one month earlier.

There is a close similarity between curves for leaf growth rates, efficiency index and net assimilation rate. The points of inflections correspond very closely and the influence of treatments is also similar. One point of difference must, however, be mentioned. The relative rate of increase in the total dry matter falls less rapidly since the plant goes on gaining in dry weight at the reproductive stage. Whereas negligible amounts of fresh leaves are produced after the first week of September, and even negative values for leaf growth rates have been obtained on account of rapid senescence and translocation of substances from the leaves to the developing bolls, still the attached leaves are synthesizing actively at this stage at about 1/3 the maximum rate as can be seen from the N.A.R.

The two maxima during the later stages of growth, exhibited prominently by N.A.R., correspond with the peaks in the percentage growth rate. Equally important is their coincidence with the commencement and the flush of flowering.

The rate of flower production. The 4-day totals of flowers produced per square yard are shown for the entire flowering period in Fig. 4 (*c*). The effect of nitrogen on flower production is very well pronounced and what is more important is that this effect is distributed over the entire flowering period in the case of the late application. The effect of late application begins with the commencement of flowering, reaches the maximum during the interval of maximum flower production, and persists till the complete cessation of flowering. The effect of early application starts somewhat later. The bulk of the increase is confined to the period of maximum flowering and the effect continues to the end. The peak is also reached eight days later in the case of early and early plus late applications as compared with control. Thus early applications have delayed flowering in contrast to the late.

The effects of nitrogen in flowering are further illustrated in Fig. 4 (*c*) (bottom). The deviations in the flowers produced under *o*, n_l, n_e, and n_e n_l. from the respective stage means of all treatments, have been plotted for each of the 15 stages. To start with, there are no differences among treatments except that the late application separates out, suggesting precocity. Other curves diverge with time, attain maximum differences after a month, and again converge to main point. Up to 24 September, higher rate of flowering is maintained in plots receiving late application. Thereafter, the plots treated before sowing gain superiority. The values for control remain below the main line, throughout. Though flowering extends over two months, more than 50 per cent of the flowers are produced during the 12-day period, from 20 September to 2 October. The effect of nitrogen also is proportionately greater during this interval.

Relative distribution of the total dry matter in parts

The effect of nitrogen on the percentage distribution of dry matter in parts at the different stages are illustrated by histograms (Fig. 5). There is no effect of early application of N at any stage so far as the ratio of stems is concerned. The relative distribution of other parts is, however, affected. The proportions of dry matter of the green leaves and the boll material are relatively higher in the last two stages under early application as compared with that of the control. The converse is true of the old leaves. n_1 plants are still more efficient in the production of flower-buds and bolls and the extra increase over the early application proceeds at the expense of stem proportion. This effect is outstanding in all the stages after the late application is given. A more rapid fall of the senescent leaves ensues in the control after 22 September, so that percentage

of green functioning leaves remaining on the plant is the least in the absence of nitrogen.

A study of the progressive changes in the relative distribution of dry matter in parts from stage to stage reveals interesting features. More than 80 per cent of the total plant weight consists of the assimilating matter when the plants are seven weeks old. As the plants advance in age the leaf weights go on falling in proportion to the non-assimilating material (stem, bolls, senescent leaves). In other words, with the advance of season increasingly larger proportions of the synthetic products of the leaf are utilized for the formation of stems and branches and less and less material is spared for leaf growth. This explains the falling leaf rates. An increasing amount is continually being incorporatd in the structural frame work which in turn does not manufacture food and resembles idle capital. Therefore, not only the leaf growth rate but also the relative rate of increase in dry matter decreases. The fall is, however, less rapid because, as explained by Heath [1937], the non-assimilating material produced by leaves is included in the total dry matter but not in the leaf.

Discussion

Nitrogen is the most potent factor that affects the growth and yield of the American cotton plants, on light sandy soils in the Punjab. Meristematic activity, extension growth, flower production, bolling, the opening of bolls and the yield, are all greatly depressed at low levels of this essential element. At the fruiting stage, deficiency of nitrogen results in the development of *tirak* symptoms. The leaves turn prematurely yellow as their nitrogen concentration falls below a critical level (2·5 per cent of the leaf dry-matter), and are ultimately shed. Growth slackens and practically ceases by the middle of September. New points are not laid rapidly and the developing sympodia are not adequately spaced. Lastly the bolls develop imperfectly and contain immature seed.

None of these symptoms appear if nitrogen is supplied in time. Even visual observations reveal prominently the differences between nitrogen-fed and control plants. The leaves in the former case remain fresh and dark green during the fruiting period in marked contrast to the untreated ones. The concentration of nitrogen in the leaves does not fall as rapidly as in the control and this forecasts the final performance of the plant. The correlated influence of nitrogen applications on the internal N-concentration in leaves and the growth, under abundant supply of water, are given in Table XIX.

TABLE XIX

Relation of percentage nitrogen content of leaves to growth

Treatment	Per cent N in leaves			Height (cm.)			Total dry weight (gm.)			Dry weight (gm of green leaves.)		
	25 Aug.	22 Sept.	20 Oct.	22 Aug.	19 Sept.	17 Oct.	25 Aug.	22 Sept.	20 Oct.	25 Aug.	22 Sept.	20 Oct.
o	2·55	1·76	1·36	70·2	99·5	103·1	276	540	717	160	204	154
n_e	3·16	2·71	1·99	76·5	117·2	129·3	313	718	1,029	180	271	258
n_l	2·70	2·57	1·91	68·2	109·8	122·2	253	628	912	147	239	236
$n_e + n_l$	3·11	3·11	2·49	75·1	117·9	133·8	323	738	1,108	184	272	290

Nitrogen application proportionately reduces senescence in leaves and prolongs leaf activity during fruiting. The plant grows as it reproduces, the internodes lengthen, bearing points increase, and bolls, which are better spaced and better fed, attain perfect development. Nitrogen stimulates co-ordinated growth in all aspects and is, therefore, mainly responsible for the significance of coefficients of correlations between development and yield, against treatments. As leaf growth rate and net assimilation rate are kept up at a higher level during vital part of plant's life supply of carbohydrates does not run short under nitrogenous manuring.

It must, however, be stated that nitrogen does not materially modify the inherent growth characteristics of the plant. The nature and trends of the growth rates are much less affected. The maxima in the treated and the untreated series are reached at the same time whether growth is expressed as percentage increase or as relative rates of increase in total dry matter or leaf weights alone. The main difference is that the growth rate falls off steeply after 1 September or so in the control, while it declines gradually during the reproductive phase in the treated series.

Prolonged growth does not imply delay in the commencement of flowering and deferred maturity.

Flowering sets in as quickly in the manured as in the unmanured plots. There is, in fact, an early tendency for slightly higher rate of flower production, if the application is made just before flowering. The time of maximum flowering is only slightly delayed by nitrogen. This is followed by a rapid decline in flower production. The bulk of the increase through nitrogen is confined to the zone of maximum flowering. The later period also contributes to the increase in the flowers produced by the early applications. The crop in the treated plots does not arrive late. Increasing trends in yield appear in the first picking and are established by the middle of December.

There are other qualitative differences between the two times of application also. Although the early application is better fitted to promote vegetative growth it also influences yield of *kapas* proportionately. Therefore the efficiency for production of seed cotton per unit dry weight is only slightly affected. The late application definitely raises the efficiency of the plant for the gain in boll material is proportionately greater than the gain in the vegetative organs. However, the two times of application do not significantly differ from each other in actual yield.

In practice, therefore, it is immaterial when the application is made provided nitrogen is deficient and it is not given too late. The last date beyond which use of nitrogenous manures would be unremunerative is a matter to be decided by further experiments. It can, however be tentatively put forward on the basis of growth data that nitrogen must become available to the plant by the time it passes through the phase of maximum growth activity, i.e. before 1 September.

Water also influences the development of the cotton plant but the response is much smaller in magnitude. Water mainly operates through increase in the extension phase but not the meristematic activity. The increase in yield under heavy watering is wholly contributed by increase in boll size. The inter-relation of water and nitrogen is important but its significance depends upon the nitrogen status of the soil. If the basic soil supplies are low or have been exhausted through intensive system of cropping water is not likely to be limiting and nitrogen alone will control growth and yields. Thus response to nitrogen would be spectacular and to water only small and additive. On the other hand, when the soil has been allowed to recuperate under the influence of natural agencies, water would begin to exercise its limiting effect. Under these conditions, unless the duty of water is simultaneously raised, augmented dressings of artificial fertilizers are likely to give but meagre responses. It would thus be worth while to raise water supply for increasing the effectiveness of nitrogen.

Potash alone or in combination has not affected plant development in any year. Evidence concerning the effectiveness of superphosphate is inconclusive. In one of the experiments the effect has been negligible, and in the other it was appreciable in the absence of both nitrogen and organic manure. In the presence of nitrogen, superphosphate was ineffective in both the years. Thus neither potash nor superphosphate acted as limiting factors. It follows, therefore, that potassic and phospahtic reserves are only slowly being depleted and the limit to their exhaustion has not been reached under normal agricultural conditions.

Summary

The investigation describes the results of two field experiments of the multiple-factor type with 4F Punjab-American cotton, on light sandy soils at the Lyallpur Agricultural Farm. In the first experiment, the main effects and interactions of nitrogen, phosphorus, potassium, organic manure and water supply were studied. In the second experiment, two times of application of nitrogen were included as distinct factors and organic manure was omitted. The remaining factors were the same as in Experiment I.

The cotton in the first experiment followed a one-year fallow. The later experiment was conducted under intensive system of cropping.

The investigation has brought out facts of physiological interest and practical value. The main findings have been summarized below.

(1) Nitrogen is the most potent factor that stimulates vegetative and reproductive development on light sandy soils. It brings about co-ordinated development of the plant in all directions and the effects are both quantitative and qualitative. Nodes, flowers, bolls, internodal length, dry weight, boll weight and yield are all affected favourably by its use. Nitrogen is, therefore, not only important for meristematic activity but also for extension growth and proper maturation of seed and lint.

(2) Nitrogen prolongs the functional activity of the plant and delays senescence. The net assimilation rate, leaf growth rate and efficiency index remain at higher levels during flowering in the N-treated plants as compared with the controls. Nevertheless, nitrogen does not materially modify the inherent growth characteristics, as the general trends with peaks and depressions are not shifted by its application.

(3) Nitrogen applied early or late does not delay the onset of flowering. The peak point is only slightly shifted. The major portion of the increase

in flowers due to nitrogen is recorded in the period of maximum flowering.

(4) The August application of nitrogen is definitely more efficient in the production of cotton per unit dry matter as compared with the one made before sowing. There is, however, only a small and insignificant difference in the actual yields in favour of the late application.

Single dressing of 50 lb. N per acre, made early or late, is more effective per unit of nitrogen than the combined dose of 100 lb. per acre.

(5) Heavy watering significantly increases the internodal length, boll size, and yield but the responses are small in magnitude. Increased water has practically no influence on the meristematic activity.

(6) There is a strong interaction between nitrogen and water on soils allowed to recuperate, by fallowing and cultivation prior to cropping. Under these conditions, nitrogen added depends on extra water supply for its full effect. If cotton follows an exhaustive crop such as *toria*, nitrogen gives larger responses even under normal water supply and effect of increased water duty is merely additive.

(7) Potassium, singly or in combination, has not shown any effect on any of the observations recorded.

(8) Phosphorus has shown beneficial effect in the absence of organic manure and nitrogen, only in the first experiment.

(9) Phosphorus or potassium neither interact with each other, nor do they enhance the utility of nitrogen. Thus they can neither replace nor augment nitrogen under field conditions.

(10) There are high correlations between yield and other characters, i.e. height, dry matter, flowers, bolls, and boll weight. Treatment yields are closely associated with the growth behaviour and the reproductive development. Developmental records, therefore, are fairly accurate guides to the ultimate performance of treatments in yield under similar cultural conditions.

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STUDIES IN INDIAN CEREAL SMUTS

VI. THE SMUTS ON *SAWAN* (*ECHINOCHLOA FRUMENTACEA*)

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(Received for publication on 4 February 1943)

Sawan (*sama, banti, sawank* or *kuthiraivalli*) is a less important cereal cultivated on a small scale in several parts of India. The grain is usually eaten by the poorer classes of people, either parched or boiled in milk with sugar, and in eastern India it is mixed with rice in the manufacture of rice beer. The crop also yields a valuable forage and it was exploited some years ago in the United States of America as a ' billion dollar grass '.

The plant was first named *Panicum frumentaceum* by Roxburgh in 1820 but seven years later, in 1827, Link transferred it to the genus *Echinochloa*. In Hooker [1897] it is referred to as *Panicum Crus-galli* var. *frumentacea* Trim. and Hitchcock [1935] calls it *Echinochloa Crus-galli* var. *frumentacea* (Roxb.) Wight. In 1928 Blatter and McCann named it *Echinochloa colona* var. *frumentacea* and six years later Fischer [1934] independently proposed the same name for it, without presumably knowing that Blatter and McCann [1928] had already done so. Sampson [1936] prefers the binomial *Echinochloa frumentacea* (Roxb.) Link which is accepted at Kew.

The crop is free from fungous diseases of major importance excepting for two quite distinct smuts which may cause damage. The first of these is *Ustilago Panici-frumentacei* Brefeld and the second *Ustilago paradoxa* Sydow and Butler. A third smut which attacks it is reported in this paper.

Ustilago Panici-frumentacei was collected by Major A. Barclay in October 1890 in the vicinity of Simla and sent to Brefeld for determination. Brefeld [1895], after consulting Lindau and Hennings, came to the conclusion that the smut was a new species to which he gave the above name. A portion of the type specimen was kindly sent to me by Dr E. Ulbrich, Kustos, Berlin Botanical Museum, in 1939 for examination.

Brefeld [1895] states that in a smutted ear not all the grains are attacked. The attacked ones are double the size of the healthy grains and they are filled with pulverulent spore masses, the individual spores being spherical, brownish and 7-9μ in diameter.

A second collection of this smut was made by C. A. Barber at Nambur, Guntur District in 1902 and was identified by Sydow and Butler [1906]. This specimen which is in the *Herbarium Cryptogamae Indiae Orientalis* agrees very well with the type. Two more collections have since then been made in the Madras presidency, one at Razole, Godavary district and the other at Nanganeri, Tinnevelly district and both of them are in the Herbarium of the Government Mycologist, Coimbatore. Portions of these collections that are available to me for examination consist of immature sori and do not show the spore structure clearly.

The second smut attacking this crop, *Ustilago paradoxa*, is likewise ovaricolous. It also attacks only a few grains in an ear but its spores are larger and have a perfectly smooth surface. While the spores of *U. Panici-frumentacei* germinate by the formation of a septate promycelium and lateral and terminal sporidia, those of this smut give out a long, branched and septate hypha without forming a true promycelium or sporidia. This smut has been recorded from Pusa in Bihar, from Sind and also the Bombay province.

In 1907 Butler collected yet another smut at Pusa on this same host which he identified as *U. Panici-frumentacei* and which he [1918] has described and illustrated. A comparison of this smut with the type at once indicated that an error had been made in its determination.

The smut causes considerable deformity of the host, turning it into a twisted mass of shoots with aborted ears. Sori occur not only in the inflorescence but on the nodes, on the young shoots and at the axils of the older leaves. The spores are spherical with thick blunt echinulations. While Brefeld's fungus is restricted to the ovaries, only a few of which are attacked, this smut aborts and completely destroys the entire inflorescence. If sori had formed on the stems, leaf axils, etc. there is little doubt that Brefeld would have mentioned that fact. The spore surface of Brefeld's smut is stated by him to be rough ; I find that it is minutely echinulate ; it is by no means covered ' with thick sharp spines '. The Pusa collection is undoubtedly not *U. Panici-frumentacei*.

Tracy and Earle [1895] described a smut on *Echinochloa Crus-galli* which forms large, irregular swellings on the nodes and in the inflorescence which is entirely destroyed. The sori are protected by a tough hispid membrane which is derived from the host plant and which ultimately ruptures disclosing the black spore masses. Tracy and

Earle [1895] named it *Ustilago Crus-galli* and, independently, Magnus [1896] first named it *Cintractia Seymouriana* but later [1896] corrected the name to *Cintractia Crus-galli* (Tracy and Earle) Magnus. The spores of the fungus are bluntly echinulate to verrucose. Two specimens distributed by Sydow (*Ustilagineen Nos. 125* and *179*) are available for examination. The smut found by Butler in 1907 at Pusa on *Echinochloa frumentacea* and identified as *U. Panici-frumentacei* is undoubtedly this smut. Neither Tracy and Earle [1895] nor Magnus [1896] speak of any, distortion of the host in describing it, which symptom is prominently featured in the Indian collection. But in the morphological characters of the spores, there is little doubt that the two smuts are identical and that the Indian smut is *Ustilago Crus-galli.* Since Magnus [1896] placed this smut in the genus *Cintractia* and McAlpine [1910] agreed with that view, the concepts about this genus have considerably changed. Only those smuts whose spores form an agglutinated, sometimes even an amorphous, mass that is difficult to separate, are at present placed in that genus. Cifferi even tries to restrict it to the smuts occurring on Cyperaceae with which view I am not inclined to agree. In any case, the spores of the smut under study are powdery and I think that there is no necessity to change the genus into which Tracy and Earle [1895] had originally placed it.

Formal descriptions of the three smuts follow:

1. Ustilago Panici-Frumentacei Brefeld, Unters. Gesammt. Mykol. 1895, 12 : 103.

Syn. *Ustilago trichophora* var. *pacifica* Lavroff, Trav. Inst. sci. Biol. Univ. Tomsk, ii, 1936.

Ovaricolous, not all ovaries in an ear attacked; ovaries swollen to twice or three times their normal size; sori covered by the seed coat which otherwise smooth and shiny, is rendered hairy; opening by means of a pore at apex. Spore masses pulverulent, deep black brown. Spores spherical, subspherical, a few ellipsoidal, 'Buckthorn brown' (Ridgway), 5·9-9·7μ in diameter, with a mean of 8·3μ; epispore thick, minutely echinulate; germinating by means of septate promycelium producing both lateral and terminal sporidia.

On *Echinochloa frumentacea*, Simla, October 1890, leg. A. Barclay (*Type*); Nambur, Guntur Dt. 9-10-1902, leg. C. A. Barber, *No. 461*; Razole, Godavery Dt. 28-8-1910; Nanganeri, Tinnevelly Dt. 12-1-1912.

Leach [1932] reports the occurrence of this smut in Nyasaland. Lavroff [1936] has made it a synonym of *Ustilago trichophora* (Link) Kze var. *pacifica* Lavroff but neither his original paper nor his specimen is available and it is not possible to confirm his conclusion. *Ustilago trichophora* was described on *Echinochloa colonum* (L.) Link, (=*Panicum colonum* L.) and it slightly resembles *U. Panici-frumentacei* but the spores of the former are larger, viz. 7·4-11·2μ, with a mean of 9·4μ. Even if it is a variety of *U. trichophora* then its name will have to be *U. trichophora* var. *Panici-frumentacei* (Brefeld) *comb. nov.* rather than the one proposed by Lavroff [1936] much later,

2. Ustilago Parradoxa Sydow and Butler, in Sydow, Ann. mycol. Berl. 1911, 9 : 144.

Ovaricolous, not all the ovaries in an ear attacked; sori not greatly exceeding the size of the normal grains, covered by a tough, slightly hairy, grey membrane, exposing a black, pulverulent spore mass on being ruptured. Spores almost spherical, oval, 'Tawny olive' (Ridgway), with granular contents, 7·8-11·2μ in diameter with a mean of 9·7μ; epispore entirely smooth, thin; germinating by the protrusion of a long, branched hypha without forming true promycelium or sporidia.

On *Echinochloa frumentacea*, Pusa, 2-9-1907, leg. E. J. Butler, *No. 890* (*Type*); Mirpurkhas (Sind), 8-10-1919, leg. G. S. Kulkarni; Bombay province, 18-9-1920. leg. M. N. Kamat.

Kulkarni [1922] has shown that this smut is externally see d borne and that it is rather common in Sind. Leach [1932] states that it occurs in Nyasaland.

3. Ustilago Crus-galli Tracy and Earle, Bull. Torry bot. Cl. 1895, 22 : 175.

Syn. *Cintractia Seymouriana* Magnus, Be r. dtsch. bot. Ges. 1896, 14 : 217.

Cintractia Crus-galli Magnus, Ber. dtsch. bot. Ges. 1896, 14 : 392.

Ustilago Panici-frumentacei sensu Butler (*nec* Brefeld), Fu ngi and disease in plants, 1918, p. 239.

Sori entirely destroying the inflorescence, also on stems especially at nodes, on young shoots and in axils of older leaves; shoot infection causing considerable defor mity resulting in a twisted mass of leafy shoots, with sometimes aborted ears; sori large, those on stem up to half an inch in diameter, swollen, covered with a hispid, grey membrane made up of host tissue on rupturing which a pulverulent, black spore mass is exposed. Spores spherical to slightly ellipsoidal, 'Mikado brown' (Ridgway), 8·9-11·9μ in diameter with a mean of 10·6μ; epispore thick, covered with blunt, dense echinulations, even verruculose; germinating by formation of a typical, septate promycelium with lateral and terminal sporidia.

On *Echinochloa frumentacea*, Pusa, 4-10-1907, leg. E. J. Butler, *No. 889*.

Summary

1. A short account of the nomenclautre of sawan, a minor cereal grown in India, is given and its correct name has been shown to be *Echinochloa frumentacea* (Roxb.) Link.

2. The crop is attacked by two smuts, *Ustilago Panici-frumentacei* and *Ustilago paradoxa*, both of which are re-described. A third smut, incorrectly identified as *U. Panici-frumentacei* is shown to be *Ustilago Crus-galli*.

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STUDIES ON THE COTTON JASSID (*EMPOASCA DEVASTANS* DISTANT) IN THE PUNJAB

IV. A NOTE ON THE STATISTICAL STUDY OF JASSID POPULATION

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(Received for publication on 11 February 1943)

AMONGST the host plants of jassids in the Punjab, cotton is the most important as regards area, cash value and general economic importance. The relationaship of the host and the pest in this crop has, therefore, been studied in great detail. The method of estimating the population of this pest on cotton is of fundamental importance and in a previous publication of this series [Verma and Afzal, 1940] one method of comparing the arithmetic means of the jassid population on any two varieties has already been described. These studies have now been amplified and are described here. The present method is of general applicability and has been employed by Williams [1937] in his studies on the number of insects caught in a light trap.

The population of the pest was estimated by the three methods on a large number of varieties from the American varietal test plots laid out according to Fisher's randomized block system during 1937-41. The procedure employed in these methods was as follows:

1. *Sweeping.* This method is useful only in ascertaining the adult population of the pest. The instrument employed was a hand-net 13 in. in diameter with a muslin bag 27 in. long and a wooden handle 27 in. in length. Adults were caught from each bed with 16 forward and 16 backward strokes of the net. The insects thus collected were later counted.

2. *Counting.* Average-sized plants (three to five) were selected from each bed in each repetition and all the living nymphs were counted on all the leaves by slowly turning them over.

3. *Fumigation.* Three to five normal plants were selected from each bed in each repetition and each plant was in turn enclosed in a fumigating chamber. A sheet of white paper was placed below the plant and the plant fumigated by pumping calcium cyanide from the hole at the top of the fumigating chamber. Dead nymphs and adults were counted on the plant as well as on the white paper.

The data thus collected was subjected to statistical analysis. It may be, however, said that in all insect census, there are great possibilities of arriving at wrong conclusions, as very often the calculated mean infestation is upset due to the swamping of results in a series of observations by very high numbers. The study of insect population over a long range of time invariably gives rise to skew distributions and covers a wide range. The degree of infestation in such cases cannot be computed merely from the arithmetic means and the application of statistical formulæ also become invalid. Thus in all such studies the data requires such a transformation as would act like the square root transformation for low numbers but like the logarithmic transformations for large numbers. Williams [1937] in his studies on the number of insects caught in a light trap has used the transformation — $y = \log_{10} (n+1)$. This function approximates to $Y=1/3\sqrt{n}$ for low numbers, and, at values of n above 10, it departs from the square root curve and approaches $Y=\log n$, from which it is practically indistinguishable at values of n above 100. The transformation prevents the swamping of results, makes the distribution normal, and affords a valid basis for estimating the insect population on different dates or different varieties.

When it is intended to compare the degree of infestation of different strains, from the insect population counted throughout the season, by the method of the analysis of variance, the same transformation must necessarily be employed. It is admitted that since the variance is proportional to the square of the mean, a very highly susceptible variety included in the experiment would increase the error vairance and thus the small differences between the varieties would be masked.

Cochran [1938] has dealt with the difficulties in analysis of variance at some length and has suggested transformations for different types of data, as without the use of one or the other transformation valid conclusions cannot be drawn. These transformations are given in Table I.

In order to find out the best transformation of the data available, the mean and the variance of the figures were worked out and by way of an example only one set of figures chosen at random from the original data is given in Table II.

TABLE I

Transformations suggested by Cochran

Distribution	Data	Relation between variance and mean	Transformation	Variance in new scale
Poisson	Small whole numbers (x) . .	$V=x$	$\sqrt{x}$	1/4
Binomial	Fraction (p)	$V=\frac{p(1-p)}{n}$	$\mathrm{Sin}^{-1}\sqrt{p}$	$\frac{821}{n}$
	Percentage (P)	$V=\frac{P(100-P)}{N}$	$\mathrm{Sin}^{-1}\sqrt{\frac{P}{100}}$	$\frac{821}{n}$
	Numbers(x)	$V=\lambda x^2$	$\log_{10} x$	$0\cdot189\lambda$

TABLE II

Mean and variance for different varieties of jassid population estimated by sweeping during 1939

Variety	Mean	Range	Variance	$\lambda=\frac{\text{Variance}}{(\text{Mean})^2}$
4F . .	163·50	382	23,804·28	0·891
L.S.S. .	171·00	443	26,364·86	0·902
100F .	208·63	608	48,129·41	1·106
289F/43 .	455·75	1678	339,159·07	1·633
124F .	603·88	1592	465,244·69	1·276
289F/K.25	1314·00	3867	2,449,084·00	1·418

It will be seen that the variance for different varieties was proportional to the square of the mean and therefore the ordinary method of analysis of variance could not be applied as there was a great probability of arriving at wrong conclusions by masking the small differences amongst the varieties. It was therefore decided to use the transformation log $(n+1)$.

In order, however, to test the validity of this transformation the analysis of variance of the original as well as the transformed data were worked out and the mean infestation and the measure of significance of the actual as well as the transformed figures are given in Table III and IV, respectively.

A comparison of these two tables reveals that the transformed figures give a much more precise measure of significance than the original data. it is seen that the relative population density on the various varieties is brought out much more precisely in the transformed figures than from the original data. When a new strain is isolated at a Plant Breeding Station in a jassid infested area, the plant breeder would like to know its reaction towards this pest and if the original data is used for this purpose the danger of masking the slight differences in resistance or susceptibility become more marked. It is, therefore, necessary to transform the figures and base the conclusions on this data.

From the data presented in Table IV a comparison of the degree of infestation on different varieties as well as a comparison of the relative efficiency of three methods of estimating the population are possible.

COMPARISON OF DIFFERENT METHODS

It will be seen from Table IV that the order of the varieties remained practically the same by the different methods in all the years. The slight differences are not such as 'to cast grave doubts on the similarity of the three methods' and thus the recommendation made earlier [Verma and Afzal, 1940] holds good. The plant breeders will, therefore, be well advised to use the cheapest method of sweeping in all their future studies.

COMPARISON OF THE VARIETIES

Amongst varieties mentioned in Table IV the main interest centres round the four commercial varieties, namely, 4F, LSS, 289F/43 and 289F/K25. It is apparent that no clear distinction can be made between 4F, LSS, and 289F/43 and that these three varieties were distinctly more resistant than 289F/K.25 which was the most susceptible variety. Amongst the new strains, Jubilee cotton, being a *desi* variety, was naturally very resistant. The rest are all strains of American cotton and 199F and 148F were of practically the same order of resistance as 4F, L.S.S. and 289F/43 while 124F was comparable to 289F/K. 25. The strains 100F, 1 26F, 186F and A.C. 31 have since been rejected on account of other undesirable characters.

SUMMARY

The insect census cannot be estimated by the arithmetic means and the utility of the logarithmic transformation employed by Williams is dealt with at length. The population of the jassids on different varieties was estimated by the three methods, sweeping, counting and fumigation, for five years (1937-41). The degree of infestation on the different varieties could not be determined by the analysis of variance of the actual data as the variances in the case of the different varieties under experiment instead of being almost

TABLE III

Mean infestations in original figures

Methods	Years	Jubilee cotton	199F	148F	4F	289F/43	L.S.S.	100F	A.C. 31	186F	124F	126F	289F/K.25	S.E. ±	d_1	d_2	Remarks
Sweeping	1937	..	..	..	288·40	307·70	247·60	341·90	..	..	..	..	557·10	30·421	85·527	113·275	L.S.S., 4F, 43F, 100F, K. 25
	1938	10·60	..	..	15·25	20·80	17·45	21·85	..	..	..	..	104·90	6·279	17·654	23·399	Jubilee, L.S.S., 4F, 43F, 100F, K. 25
	1939	..	..	..	163·50	455·75	171·00	208·63	..	..	603·88	..	1314·00	195·339	560·783	752·500	4F, L.S.S., 100F, 43F., 124F., K. 25
	1940	..	..	..	89·46	135·15	156·23	..	126·77	182·38	..	283·62	261·77	26·246	74·085	98·396	4F, A.C. 31, 43F L.S.S., 186F, K. 25, 126 F
	1941	..	261·83	293·83	368·50	297·33	325·17	..	..	..	800·17	..	802·33	57·377	162·123	215·515	199F, 148F, 43F, L.S.S., 4F, 124F, K.25
Counting	1937	..	..	..	86·55	95·35	66·05	115·15	..	..	..	..	268·05	18·531	52·282	69·421	L.S.S., 4F, 43F, 100F. K.25
	1938	1·90	..	..	4·85	5·75	4·50	7·55	..	..	..	..	69·35	4·344	12·213	16·188	Jubilee, L. S. S., 4F, 43F. 100F. K.25
	1939	..	..	..	53·63	90·00	55·75	56·88	..	..	116·38	..	277·25	58·705	168·533	226·149	4F, L.S.S., 100F, 43F, 124F, K. 25
	1940	..	..	..	72·71	109·64	85·86	..	123·71	121·21	..	185·71	332·29	30·702	86·577	114·929	4F, L.S.S., 43F, 186F, A.C. 31, 126F, K. 25
	1941	..	281·92	263·75	399·08	265·42	304·33	..	..	..	949·17	..	1078·58	80·186	160·212	212·974	148F, 43F, 199F, L.S.S., 4F, 124F, K. 25
Fumigation	1937	..	..	..	134·17	148·52	115·44	178·78	..	..	..	..	376·74	24·455	68·927	91·441	L.S.S., 4F, 43F, 100F, K. 25
	1938	3·31	..	..	9·31	9·44	9·44	12·63	..	..	..	..	103·38	5·324	15·021	19·945	Jubilee, L.S.S., 4F, 43F, 100F, K. 25

TABLE IV

Mean infestations in transformed scale

Methods	Years	Jubilee cotton	199F	148F	4F	289F/43	L.S.S.	100F	A.C.31	186F	124F	126F	289F/K.25	S.E. ±	d_1	d_2	Remarks
Sweeping	1937	..	..	..	1·8197	1·8801	1·7288	1·9510	..	..	..	..	2·1763	0·0573	0·1615	0·2144	L.S.S., 4F, 43F, 100F, K. 25
	1938	0·7551	..	..	0·9586	1·0779	1·0544	1·1527	..	..	..	..	1·7703	0·0426	0·1198	0·1588	Jubilee, 4F, L.S.S., 43F, 100F, K. 25
	1939	..	..	..	1·9889	2·2583	1·9908	2·0646	..	..	2·4309	..	2·7224	0·0379	0·1087	0·1458	4F, L.S.S., 100F, 43F, 124F, K. 25
	1940	..	..	..	1·5520	1·7229	1·6930	..	1·7024	1·6941	..	1·9825	2·0350	0·0428	0·1207	0·1603	4F, L.S.S., 186F, A.C. 31, 43F, 126F, K.25
	1941	..	2·1168	2·1260	2·1990	2·1370	2·2349	..	..	..	2·5581	..	2·5803	0·0393	0·1110	0·1476	199F, 148F, 43F, 4F, L.S.S., 124F, K.25
Counting	1937	...	..	..	1·6257	1·6164	1·5233	1·7701	..	..	..	..	2·0912	0·0279	0·0788	0·1046	L.S.S., 43F, 4F, 100F, K. 25
	1938	0·3494	..	..	0·6020	0·6822	0·6054	0·7927	..	..	..	..	1·6417	0·0463	0·1301	0·1724	Jubilee, 4F, L.S.S., 43F 100F, K. 25
	1939	..	..	..	1·4714	1·6800	1·4853	1·5456	..	..	1·7938	..	2·1169	0·0623	0·1790	0·2402	4F, L.S.S., 100F, 43F 124F, K. 25
	1940	..	..	..	1·5165	1·6103	1·5872	..	1·6401	1·6513	..	1·8877	2·0925	0·0603	0·1702	0·2259	4F, L.S.S., 43F, A.C. 31, 186F, 126F, K. 25
	1941	..	2·1129	2·1010	2·1750	2·1129	2·1456	..	..	..	2·6197	..	2·6816	0·0456	0·1287	0·1711	148F, 199F, 43F, L.S.S., 4F, 124F, K. 25
Fumigation	1937	..	..	..	1·7625	1·7740	1·6703	1·8579	..	..	..	..	2·1715	0·0190	0·0537	0·0712	L.S.S., 4F, 43F, 100F, K. 25
	1938	0·5396	..	..	0·9126	0·9685	0·9157	1·0637	..	..	..	..	1·9522	0·0397	0·1120	0·1487	Jubilee, 4F, L.S.S., 43F, 100F, K. 25

the same were of unequal magnitude and proportional to the square of the means. The data was, therefore, transformed to $\log_{10}(n+1)$.

It was found that the order of the susceptibility of all the varieties remained practically the same by the three methods and hence the breeders have been advised to use sweeping, which is cheapest and simplest of the three.

It was found that 4F, LSS and 289F/43 were equally resistant and that 289F/K25 was the most susceptible variety. Among the other American strains 199F and 148F need only be mentioned. These were practically of the same order of resistance as 4F, LSS and 289F/43. Jubilee cotton, a *desi* variety, was, however, the most resistant strain.

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STUDIES ON FRUIT AND VEGETABLE PRODUCTS

III. ASCORBIC ACID (VITAMIN-C) CONTENT OF SOME FRUITS, VEGETABLES AND THEIR PRODUCTS

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EVER since Svirbely and Szent Gyorgi [1932] showed experimentally that vitamin C was identical with hexuronic acid or ascorbic acid, its reducing property has been utilized in its estimation by the modified Tillman 2 : 6 dichlorophenol indophenol indicator method as developed by Birch, Harris and Ray [1933]. On account of its importance in nutrition, the estimation of vitamin C in fruits, vegetables and their numerous products, has in recent years been the subject of a great deal of investigation. There is absolutely no record of the vitamin-C content of the different kinds of fruit and vegetables grown in Baluchistan. In an investigation of this nature, factors like soil, climate, variety, method of handling, etc. have a profound influence on the vitamin-C content of the material. This attempt to record the findings on the subject is, therefore, fully justified. Further, the experimental data obtained have an intrinsic value in themselves.

In a study of the ascorbic acid content of some English fruit and vegetables, Olliver [1938] found that in the case of black currants, gooseberries and strawberries, the maximum vitamin-C content is obtained by early picking. On any one day of picking, however, the concentration is higher in the riper than in the less ripe fruit. In the case of gooseberries, etc., variety may greatly affect the vitamin-C content. In America, Wheeler, Tressler and King [1939] have carried out an exhaustive series of investigations on the vitamin-C content of numerous vegetables and recorded their approximate vitamin-C content in milligrams per gram of the material.

In recent years, various workers in India are engaged in studies on the vitamin-C content of fruits and vegetables. Damodaran and Srinivasan [1935] studied the vitamin-C content of some Indian plant materials like drumstick (*Moringa oliefera* Lamsk), Cashewapple (*Anacardium occidentale* Linn), *ber* (*Zizipus jujuba* Jus.), etc. Their experimental findings not only showed the existence of strikingly rich sources of vitamin-C among materials not examined till then, but also threw interesting light on the variations in the conditions in which the vitamin exists in plants. Ahmed [1935] chemically determined the vitamin-C content of a number of Indian fruits and vegetables. Mitra, *et al.* [1940] estimated the ascorbic acid content of some 96 fruits and vegetables grown in Bihar. In the mango, the ascorbic acid content of the skin was found to be twice as much as that of the pulp [Rama Sarma and Banerjee, 1940]. Workers in the Nutrition Research Laboratories at Coonoor are also engaged in studies on this subject.

All the world over, the attention of research workers is, however, now turned to a study of the changes in the vitamins during the different stages of processing of the numerous fruit and vegetable products. The literature on this subject is vast and requires careful sifting to secure concrete data. There are, however, a few reviews on the subject. 'Vitamins in Canned Foods' is the title of an exhaustive and critical paper on the subject by Kohman [1937]. In a review of the effect of processing on vitamins in fruits and vegetables, Fellers [1936] pointed out that ordinary storage and to a lesser extent cold storage for long periods in air, cause serious loss of vitamin C. Sun-drying is more destructive to vitamin C than artificial dehydration. Fermentation of fruits and vegetables is injurious to vitamin C. During canning, the more acid fruits retain more of vitamin-C than the non-acid vegetables.

Olliver [1936], who studied the effect of cooking and canning on the ascorbic acid content of fruits and vegetables, came to the conclusion that limits of variations rather than fixed values should be given to the vitamin-C content of fruits and vegetables. The percentage of ascorbic acid destroyed in both cooking and canning is comparatively small. Some plant tissues showed apparent gain of ascorbic acid on heating, a result of considerable interest in view of the recent work by Reedman and McHenry [1938] on combined ascorbic acid in plant tissues.

Mac Linn and Fellers [1938] noticed that tomato varieties and strains showed a considerable range in ascorbic acid content (74 to 249 international units per ounce; 1 international unit of vitamin C = 0·05 mg. pure ascorbic acid). The outside flesh and skin of the fruit were found to contain most of the ascorbic acid, but its highest concentration was in the seeds and in the gelatinous material of the locule section. About 25 per cent of the

original ascorbic acid present in tomato juice was destroyed when the juice was concentrated to prevent separation of suspended solids. Tomato juice stored for 400 days both in the dark and in the light did not lose more than 25 per cent ascorbic acid.

According to Charley [1939], syrup from the Baldwin variety of black currant contains as much as 101·3 mg. ascorbic acid per 100 c.c. Sills [1940] noticed that sulphur dioxide exerted the greatest preservative action on ascorbic acid content in English fruit juices and syrups. Joslyn [1941] noticed that in the case of citrus juices, sulphur dioxide was not only an excellent antioxidant, but also a preservative of vitamin-C and colour, contrary to other findings. Lal Singh and Girdhari Lal [1940] have determined the ascorbic acid content of tomato juice.

The present paper deals mainly with the effect of various manufacturing processes on the ascorbic acid content of some important fruit and vegetable products.

Material and methods

Different kinds of fruits and vegetables employed in this investigation were mostly obtained from the Government Fruit Experiment Station, Quetta, while for comparative purposes market samples also were analysed in certain cases. The material was, therefore, of known origin and the results obtained were of great use in interpreting the effect of variety, soil factor, climate, method of handling, etc. on the ascrobic acid content of the material.

The ascorbic acid content of the fresh as well as the processed fruit or vegetable was estimated by the modified Tillman 2 : 6 dichlorophenol indophenol indicator method as developed by Birch, Harris and Ray [1933]. In the case of the fresh material, trichloracetic acid was employed for getting the extract, while in the case of juices and syrups, the press extract itself was taken for the estimation of the ascorbic acid. The details are, however, given briefly in the following paragraphs.

The indicator solution

Harris and Ray [1933] recommend 0·1 gm. of the indicator in 50 c.c. water, i.e. a 0·2 per cent solution. In the present case, however, 0·145 gm. of the indicator was dissolved in water and made up to 50 c.c. to give a 0·01 M solution. The indicator solution was standardized against ascorbic acid solution which was itself standardized against iodine solution. At the end point of titration, the blue colour of the indicator changed sharply into red or slightly brownish red tint and remained so for 2-3 minutes.

Extraction of ascorbic acid

The ascorbic acid in the case of most fruits and vegetables is bound up with the tissues in varying degrees and its complete extraction is not an easy process. The cell tissues are to be broken before the solvent can extract it. The method adopted for the extraction was briefly as follows :—About 10 gm. of the fresh material was cut into fine pieces with a stainless steel knife and crushed in a glass mortar using 5 gm. of chemically pure sand, to break up the cells, and 6·25 c.c. of 20 per cent trichloracetic acid solution. The extract was filtered rapidly through muslin cloth. In some cases, the extraction was repeated twice or thrice. The combined extracts were made up to 25 c.c. so that the final concentration of trichloracetic acid in the final extract was 5 per cent.

Trichloracetic acid helps to precipitate protein matter and break up the cell walls releasing the ascorbic acid. Further, it may also stabilize the vitamin by having an inhibitory effect on the oxidizing system in the broken tissue. It is, however, not definitely known if trichloracetic acid extracts the vitamin completely from the fruit or vegetable tissue. A few experiments in this direction were carried out by varying the time of grinding, number of extractions, concentration of trichloracetic acid, and also by applying heat, etc. Olliver [1938] recommends metaphosphoric acid in addition to trichloracetic acid as it helps to prevent oxidation. In the case of fruit juices and syrups, they were titrated directly with the indicator solution. In most cases, the average of three readings was taken to calculate the ascrobic acid content. The results thus obtained for the ascorbic acid represent, therefore, what occurs in practice in the preparation of these products.

The ascorbic acid content of some important fruits and vegetables and their products are given in Tables I and II. It will be noticed that white clingstone peaches contain nearly twice as much ascorbic acid as yellow freestone peaches. Limes are rich in vitamin C and the juice contains nearly 44 mg. of it in 100 c.c. Tomatoes are quite rich in their ascorbic acid content. Green and unripe tomatoes contain only 18-20 mg. of the acid, while the ripe ones contain as much as 30 mg. per 100 gm. The juice content of tomatoes obtained by hot pressing is 73·06 per cent and the ascorbic acid content of the juice is 29·12 mg. per 100 c.c. indicating thereby that most of the acid is concentrated in the juice that can be separated by mere hot pressing. When the 'hot' pressed juice was allowed to stand overnight in an open vessel, there was a loss of 1·41 mg. of ascorbic acid only. When fresh cold-expressed juice was filtered and the filtrate taken for the estimation of ascorbic acid,

TABLE I

Ascorbic acid content of some important fruits

Experiment No.	Particulars	Ascorbic acid content (mg.)	Remarks
1	White clingstone peach, fully ripe (*Prunus persica*)	11·96/100 gm.	From Fruit Experiment Station
2	Parvin-Yellow free stone peach, fully ripe	6·02/100 ,,	Ditto.
3	*Kagzi* lime—good quality fruit (*Citrus medica acida*)	43·87/100 ,,	Market sample
4	Water melon juice (5·8 Deg. Brix. and 0·04 per cent acidity, as Citric acid) (*Citrullus vulgaris*)	5·27/100 c.c.	
5	Water melon seed, air dried	3·37/100 gm.	Not a rich source of vitamin C
6	Tomatoes (local) large red, fully ripe (*Lycopersicum esculentum*)	30·26/100 c.c.	Juice was pressed in the cold
7	Do. Yellow ripe only (acidity of juice 0·52 per cent as citric acid)	17·67/100 c.c.	Unripe tomatoes; hence the low value
8	Do. Green and unripe	19·83/100 c.c.	
9	Do. Ripe, red (Trichloracetic acid extract)	23·03/100 gm.	
10	Do. Fully ripe, juice extracted by the 'hot process' as for preparing tomato juice	29·12/100 c.c.	The juice content of tomatoes (by pressing) is 73·06 per cent. The juice appears to contain almost the whole of the ascorbic acid
11	Do. The juice from Expt. 10 allowed to stand overnight	27·71/100 c.c.	
12	Do. Juice freshly expressed in the cold and filtrate taken for estimation	32·91/100 c.c.	The clear serum contains the whole of the ascorbic acid in tomato juice
13	Peach squash (55 Deg. Brix. and 1·0 per cent added acidity, as citric acid; preserved by SO_2)	11·0/100 c.c.	Prepared from white peaches

TABLE II

Ascorbic acid content of some vegetables

Experiment No.	Particulars	Ascorbic acid content (mg.)	Remarks
1	Lettuce, fresh and green (*Lactuca sativa*)	17·01/100 gm.	From Fruit Experiment Station Garden
2	Spinach, fresh and green (*Spinacea oleracea*)	63·54/100 gm.	Do. Rich in vitamin C
3	Potato, fresh young, not peeled (Local variety) (*Solanum tuberosum*)	24·57/100 gm.	
4	Green chilli, fresh and green (*Capsicum acuminata*)	74·87/100 gm.	From Fruit Experiment Station Garden. This is a remarkable observation
5	Brinjal, fresh, small, tender purple coloured (*Solanum melongena*)	3·76/100 gm.	Ditto.
6	*Karela* (*Momordica charantia*, Cucurbitaces)—		
	(*a*) Small, tender, green $2\frac{1}{2}$ in. × $\frac{3}{4}$ in. diam Juice pressed in the cold through cloth	175·5/100 c.c.	
	(*b*) Same after two days storage at room temperature (trichloracetic acid extract)	188·0/100 gm.	
	(*c*) Same as in (*a*) cut into slices and sun dried (20 per cent yield)	29·81/100 gm. of fresh vegetable, 149·05/100 gm. of dried vegetable	There is thus a loss of 83·0 per cent of ascorbic acid as a result of sun drying
	(*d*) Old, yellowish green and brittle, 7 in. × $1\frac{3}{4}$ in. in size	95·72/100 gm.	Young and tender Karela contains nearly twice as much ascorbic acid as the ripe and brittle one

it was noticed that it contained slightly more of the acid than the unfiltered juice. This slight increase in the value might be due to the fact that during filtration of a certain volume of the juice the insoluble particles are removed, thereby decreasing the volume of the filtrate, and consequently, a slightly less volume of the filtrate will be required to titrate a given volume of the indicator. The experiment also indicates that the clear serum contains almost the whole of the ascorbic acid in tomato juice, the insoluble pulp containing a negligible quantity of it. Cold-pressed tomato juice was also slightly richer in ascorbic acid than the hot-pressed juice, showing thereby a slight loss of the acid during the short period of heating prior to pressing.

In the case of vegetables, spinach, green chilli and *karela* (*Momordica charantia* Cucurbitacea) are very rich in ascorbic acid. It is a remarkable observation that green chillies grown locally contain as much as 74·87 mg. and *karela* 188·0 mg. of the acid per 100 gm. of the tissue. Lettuce and potatoes contain 17·01 and 24·57 mg. respectively per 100 gm. of the fresh tissue. The juice of *karela*, when pressed in the cold, is very rich in ascorbic acid and contains 175·5 mg. of it per 100 c.c. When the vegetable is over-ripe and yellow, its ascorbic acid content is low, being only about 50 per cent of that of the fresh tender vegetable. When the fresh tender vegetable was cut into pieces and dried in the sun without any further preliminary treatment, the yield of the dried product was 20 per cent of the fresh vegetable and it contained 149·05 mg. of ascorbic acid per 100 gm. of the powder, or 29·81 mg. per 100 gm. of the of fresh vegetable. There was, therefore, a loss of nearly 83·0 per cent of the acid during ordinary sun-drying. In spite of this, even the sun-dried powder contains nearly 30 mg. of ascorbic acid per 100 gm. which compares favourably with tomato juice which is well known for its vitamin-C content. *Karela* might prove an easily available and rich source of vitamin-C in the production of foodstuffs containing the added vitamin. Further experiments are needed to find out if by modifying the process of drying, the loss of ascorbic acid content of the vegetable can be minimized. The bitter nature of the vegetable might prove a handicap in its widespread use in the preparation of vitamin-fortified foodstuffs, but it should be possible to get over this difficulty also. This is, however, a subject that requires further investigation.

Ascorbic acid content of tomato juice

In view of its importance as a source of vitamin-C, tomato juice and related products have been the subject of a series of investigations by American workers [Mac Linn and Fellers, 1938]. During the 1939 and 1940 seasons, a number of batches of tomato juice were prepared and bottled using high quality tomatoes grown at the Fruit Experiment Station, Quetta. The method of preparation was as follows :

Fully ripe tomatoes were washed with cold water sprays, cut into four pieces and heated quickly in an aluminium vessel and kept at the boiling temperature for 5 minutes to soften the pulp. The hot pulp was then rubbed by means of glass rubbers through loose mesh muslin cloth spread over 16 mesh monel metal sieves. The juice thus screened was weighed and salt added to the extent of 0·9 per cent by weight. The juice was brought to a boil, and filled hot into sterile glass bottles of 24 oz. capacity which were then closed with crown corks and sterilized for 35 minutes in boiling water. At the end of the process, the bottles were cooled slowly by running out the hot water from the tank. The degree Brix, acidity and ascorbic acid content of the juice were determined in all cases. The data are given in Table III. It will be noticed that the Brix value of the juice varies from 6·0 to 8·3 degrees, while the percentage acidity varies from 0·48 to 0·74. The ascorbic acid content has, however, a greater range of variation. Early in August, the ascorbic acid content of the juice was only 29 mg. per 100 c.c., while about a week later when the tomato season was at its highest, it rose to 53 mg., indicating thereby that fully ripe tomatoes at their peak period are considerably richer in ascorbic acid than the early ones even when they are fully ripe. When ripe tomatoes are picked and kept in ordinary storage for two to three days only, there is only a very slight loss of ascorbic acid. Longer storage, however, may considerably increase this loss as reported by Fellers [1936]. During the 1939 season, the samples of tomatoes were collected towards the end of July when the ascorbic acid content of the juice was 26-28 mg. per 100 c.c. There was a tendency for this value to rise with advancing season. The slight increase in the ascorbic acid content of tomato juice cocktail was mostly due to the added acid through the addition of lemon juice, chilli powder and spices to plain tomato juice to convert it into the cocktail.

A well known brand of tomato juice packed in plain cans was found to contain only 12·5 mg. of ascorbic acid per 100 c.c. In our experiments, the freshly bottled juice was far higher in its ascorbic acid content. There was, however, a certain amount of loss during ordinary storage in white glass bottles for long periods.

The results of a series of experiments on the changes in ascorbic acid content of tomato juice during preparation as well as storage in white glass

bottles under sterile conditions are given in Table IV.

It will be noticed that there is comparatively little loss of ascorbic acid content during the first 20 min. when the juice is kept in stoppered glass flasks. After that period, there is a slight fall in the value and at the end of 43 hrs., the loss is nearly 35 per cent of the original value. The ascorbic acid content of tomato juice decreases with increasing period of storage of fully ripe tomatoes. It is, therefore, desirable not to keep fully ripe tomatoes long in storage before preparing the juice. There is a considerable loss of ascorbic acid in bottled tomato juice during ordinary storage. In one instance, the original ascorbic acid content of the juice was 28·65 mg. per 100 c.c., but when bottled and stored at ordinary temperature for about 11 months, the value was only 16·54 mg. per 100 c.c. indicating a loss of nearly 42·6 per cent of the vitamin.

TABLE III

Ascorbic acid content of tomato juice

Experiment No.	Date	Particulars	Juice: Yield	Juice: Deg. Brix.	Juice: Acidity per cent	Juice: Ascorbic acid	Remarks
					Per cent as citric	mg. 100 c.c.	
1	10-8-39	Large ripe, red, select tomatoes local variety	75·0	7·0	0·57	29·12	Juice screened through monel metal sieve
		Ditto . .	..	..	..	28·7	After adding salt and heating to 200°F. before filling into bottles
		Ditto . .	..	..	..	28·7	After standing overnight in an open bottle
2	11-8-39	Large, red, select tomatoes, slightly under-ripe	57·1	6·2	0·62	28·5	
3	15-8-39	Tomatoes fully ripe . .	61·9	6·5	0·48	52·65	
4	19-8-39	Tomatoes ripe . . .	71·5	6·7	0·73	40·51	Splitting of the tomato had begun
5	21-8-39	Same as in Expt. (4) stored in trays at room temperature	52·8	6·8	0·57	40·51	There was not any change in the ascorbic acid content as a result of further ripening after picking]
6	23-8-39	Tomatoes picked on 22 August 39	70·0	6·2	0·75	35·10	
7	30-8-39	Ripe tomatoes . .	67·4	6·3	0·63	40·51	
8	1-9-39	Tomatoes picked on 31 August ; ripe	70·4	6·3	0·74	47·86	
9	9-9-39	Tomatoes picked on 8 September ; ripe	66·6	6·0	0·70	43·87	
10	13-9-39	Tomato juice, commercial brand	..	..	..	19·5	A well-known brand of tomato juice in cans was analysed for comparative study
11	15-7-40	Ripe tomatoes of good quality	66·7	6·1	0·56	26·34	
12	20-7-40	Ditto . .	75·2	8·3	0·65	27·71	Salt was added before taking the Brix. reading
13	28-7-40	Ditto . .	65·9	6·5	0·65	30·97	Spices were added to prepare tomato juice cocktail
14	29-7-40	Ditto . .	70·7	6·5	0·63	37·61	Ditto.

TABLE IV

Changes in the ascorbic acid content of tomato juice

Experiment No.	Particulars		Ascorbic acid content mg./100 c.c.	Remarks
1	Tomato (local variety) large red, fully ripe; juice pressed cold and filtered rapidly through muslin cloth—		..	
	(1 c.c. indicator = 1·053 mg. of ascorbic acid)			
Time after extraction		1 c.c. indicator = c.c. juice		
	3 minutes	3·48	30·26	The juice was kept in a stoppered glass flask at room temperature
	10 ,,	3·30	31·91	
	20 ,,	3·32	31·72	
	25 ,,	3·40	30·96	
	60 ,,	3·46	30·43	
	43 hours	5·10	20·65	There is a loss of about 35 per cent of the original value
2	Tomato from Expt. No. (1) ripened further for two days in the open		28·77	The ascorbic acid content decreases slightly as a result of further ripening after picking
3	Do. after four days ripening		25·07	
4	Tomato juice bottled on 11 August 1939 and kept in ordinary storage till 17 July 1940. Original ascorbic acid content of juice 28·65 mg./100 c.c.		16·54	There was thus a loss of 42·6 per cent of ascorbic acid content during a period of storage for about 11 months

SUMMARY

An investigation has been carried out into the ascorbic acid (vitamin-C) content of a number of important fruits and vegetables and some of their products. The ascorbic acid estimations were carried out by titration against standard 2 : 6 dichlorophenol indophenol indicator.

White clingstone peaches contain nearly twice as much ascorbic acid as yellow freestone peaches.

Green and unripe tomatoes contain only 18-20 mg., while the ripe ones contain as much 30 mg. of ascorbic acid per 100 gm. of the tissue.

Almost the whole of the ascorbic acid present in tomatoes is in the juice that can be separated by cold pressing. The clear serum contains the maximum amount of the acid, while the filterable insoluble pulp contains almost nil. There is only a slight loss of ascorbic acid during the hot process of extraction.

The ascorbic acid content of tomato juice increases with the advance of the tomato season and is the maximum somewhere near the peak period of the season. When ripe tomatoes are picked and kept in ordinary storage for two to three days only, there is only a very slight loss of ascorbic acid. Longer storage may, however, considerably increase this loss.

There is very little loss of ascorbic acid in hot-pressed tomato juice during the first 20 min. of storage, after which there is a gradual fall and at the end of about 43 hrs., the loss is nearly 35 per cent. There is, however, considerable loss of ascorbic acid in bottled tomato juice during ordinary storage, the loss being as much as 42·6 per cent during storage for a period of 11 months.

Among vegetables brinjal contains 3·76 mg., lettuce 17·01 mg., spinach 63·54 mg. and potato 24·57 mg. of ascorbic acid per 100 gm. of the fresh, tender vegetable. Green chillies are remarkably rich in ascorbic acid, in one instance, the value being as high as 74·87 mg. per 100 gm. of the tissue. *Karela* (*Momordica charantia* Cucurbitacea) is the richest source of ascorbic acid among the vegetables examined. The fresh tender vegetable contains 188·0 mg. of ascorbic acid per 100 gm. of the tissue, while the cold-pressed juice contains 175·5 mg. of the acid per 100 c.c. Old and brittle *karela*, however, contains only about 50 per cent as much ascorbic acid as the young and tender

vegetable. During sun-drying, there is a loss of nearly 83·0 per cent of ascorbic acid in the case of young and tender *karela*, the dried vegetable containing 149·05 mg. of the acid per 100 gm. which corresponds to only 29·8 mg. of the acid per 100 gm. of the original fresh material.

Acknowledgements

It is a great pleasure to acknowledge my indebtedness to the Imperial Council of Agricultural Research for financing this investigation under a general scheme of research on fruit canning and preserving in Baluchistan. My thanks are also due to Mr A. M. Mustafa, M.B.E., Director of Agriculture, Baluchistan, for taking a keen interest in my work.

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ARIATION IN THE MEASURABLE CHARACTERS OF COTTON FIBRES

VI. VARIATION IN THE UNCOLLAPSED DIAMETER OF THE COTTON FIBRE

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Of the various measures that are employed to estimate the fineness of the cotton fibre, the diameter of the uncollapsed fibre appears to be the closest approximation as it gives the diameter of the undisturbed fibre cell. Equivalent to it is the diameter of the fibre swollen in 18 per cent caustic soda solution, as has been shown by Calvert and Summers [1925] and others. But the presence of immature fibres, which do not swell into rounded cylindrical shape in the caustic soda solution, would create some errors. Neglecting these immature fibres from measurement would overcome the defect, as Iyenger and Ahmad [1942] found that the mean diameter is practically the same for the mature, half-mature and immature fibres in a sample of cotton. Generally speaking, therefore, the diameter of the swollen fibre could be used as a measure of fineness. In field laboratories where fresh bolls could be procured, the uncollapsed diameter can be used as is being done in Egypt [Brown *et al.* 1932].

In this method, however, the difficulty of proper sampling is a drawback, because the wet fibres cannot be mixed thoroughly as is done in the case of dry lint. A tuft from a certain region on the seed is to be taken for the test. This raises the question of the variation of the fibre diameter on the surface of the seed. Work of Koshal and Ahmad [1932] has shown that the length and fibre weight vary considerably in the different regions of the seed. Similar variability in the fibre maturity and standard fibre weight was found by Iyengar [1941]. As the standard fibre weight is a measure of the diameter, it is to be expected that the latter also varies in the different regions of the seed. To study the extent of this variation is the object of the present work. For this purpose the uncollapsed diameter of the fibre was determined at the three regions (1) micropylar end, (2) right side (raphe facing the observer and micropyle pointing upwards), and (3) the chalazal end. These three regions would be sufficient for our purpose as the previous work has shown that the variation of the fibre characters is greatest between the micropylar and chalazal ends, the right side having nearly the same value as for the other regions.

A fairly mature boll plucked from the plant was immediately cut open and the locks were placed under water. The middle seed of one lock was taken out, the fibres were gently teased out by means of needles and a tuft of about 80 to 260 fibres sprouting exactly on the region required was separated and pulled out, the whole operation being done under water. The fibres in the tuft were arranged parallel on a Gulati and Ahmad [1935] slide, mounted in a mixture of equal proportions of glycerene, alcohol and water and examined. No fixative was used as only one or two bolls were examined each day.

The results obtained in the case of 13 bio-types of *G. hirsutum* grown under irrigation and four of *G. arboreum* and two of *G. herbaceum* grown under rain-fed conditions are recorded in Table I. One tuft taken from each of the three regions on one seed was examined for each boll.

It will be seen in the irrigated varieties of *hirsutum* that (1) in every case the micropylar end indicates a significantly higher value than either of the other two regions and (2) in eight cases, namely 3, 4, 7, 13, 14, 15, 17, and 18, the right side has a significantly higher value than the chalazal end. When the mean values for the different regions in all the irrigated cottons are considered, the micropylar end is found to be significantly greater* than the right side or the chalazal end.

The coefficient of variation is found to vary from 10·8 to 21·7 per cent with an average 15·8 per cent. The right side appears to have a lower coefficient of variation than the other two regions. The variability, which is of the same order as that found by Koshal and Ahmad [1939] for the swollen diameter, indicates that an examination of about 200 fibres would give a standard error of about 1·1 per cent.

Amongst the rain-grown cottons, the differences between the micropylar region and the other regions are not so high as indicated by the irrigated hirsutums. While in the latter case the difference was significant in all cases, in the case of the rain-grown cottons only four samples (Nos. 19, 21, 22 and 25) out of 10 record significantly higher values for the micropylar end over the right side. Between the micropylar end and the chalazal end, however, all the differences except the last three are significant. In all cases except two (Nos. 21 and 26) the right side has significantly higher value

* Significance was estimated according to student's method

TABLE I

Uncollapsed diameter in the different regions of the seed in μ

	No.	Strain	Micropylar end				Right side				Chalazal end			
			No. of fibres	Value	S.E.	C.V. per cent	No. of fibres	Value	S.E.	C.V. per cent	No. of fibres	Value	S.E.	C.V. per cent
Irrigated cottons		*G. hirsutum*												
	1	X3915 Q. 7	242	24·9	0·211	13·1	217	21·4	0·212	14·6	233	21·9	0·223	15·2
	2	,, Q. 10	144	24·7	0·271	13·3	164	21·8	0·239	14·0	179	21·4	0·230	14·3
	3	,, Q. 11 (1)	264	23·4	0·204	14·1	164	21·4	0·212	12·7	250	20·1	0·220	17·3
	4	,, Q. 11 (2)	188	24·3	0·191	10·8	263	21·5	0·163	11·7	230	20·7	0·226	16·7
	5	,, Q. 12	121	24·5	0·337	15·1	247	21·0	0·195	14·6	206	20·5	0·253	18·0
	6	X4383 B. 15 (1)	178	24·5	0·278	15·1	178	20·6	0·249	16·1	169	20·3	0·248	15·8
	7	,, B. 15 (2)	229	24·3	0·228	14·2	233	22·4	0·183	12·4	209	21·4	0·202	13·6
	8	,, B. 33	172	24·7	0·336	17·8	274	21·5	0·204	15·7	210	20·8	0·211	14·7
	9	,, B. 53	118	27·6	0·640	21·7	143	22·3	0·244	13·3	169	22·9	0·256	14·5
	10	,, G.	128	23·2	0·423	20·7	183	20·7	0·229	14·9	204	20·3	0·236	17·3
	11	X4463 A. 1	194	24·3	0·269	15·3	226	20·9	0·222	16·0	170	20·2	0·318	20·7
	12	,, A. 2 (1)	135	23·6	0·318	15·9	296	20·2	0·211	18·0	210	20·2	0·201	14·4
	13	,, A. 2 (2)	157	25·4	0·322	15·9	128	22·6	0·271	13·6	223	21·1	0·234	16·6
	14	,, A. 3	175	24·1	0·310	17·1	189	22·2	0·276	17·0	140	20·7	0·363	20·7
	15	,, A. 4	166	23·8	0·231	12·5	152	22·2	0·231	12·9	168	20·4	0·282	18·0
	16	Co. 2 (1)	175	27·1	0·468	22·8	239	22·6	0·197	13·4	136	23·2	0·359	18·6
	17	,, (2)	145	25·6	0·360	17·0	125	21·6	0·377	19·5	169	20·3	0·311	19·7
	18	,, (3)	168	24·2	0·320	17·2	209	22·2	0·250	16·2	127	20·2	0·358	19·9
		Mean		24·7		16·1		21·6		14·8		20·9		17·1
Rain-grown-cottons		*G. herbaceum*												
	19	2919	87	28·2	0·717	23·8	183	24·5	0·299	16·5	119	22·6	0·415	20·0
	20	4714	84	23·6	0·452	18·5	161	24·3	0·400	20·9	166	21·8	0·372	22·0
		G. arboreum												
	21	C. 6—4 (1)	83	25·0	0·719	26·6	161	20·6	0·226	13·8	184	21·4	0·269	17·0
	22	,, (2)	162	23·1	0·357	19·6	184	22·0	0·303	18·6	151	20·6	0·325	19·4
	23	,, (3)	93	22·5	0·484	20·8	170	21·6	0·280	17·0	153	20·0	0·300	18·5
	24	C. 22—1	79	23·8	0·600	22·3	101	23·1	0·396	17·2	184	21·2	0·314	20·1
	25	L. 3 4/4 (1)	153	23·5	0·385	20·2	197	21·4	0·221	14·5	173	18·4	0·339	24·2
	26	,, (2)	102	21·7	0·448	20·8	216	21·2	0·256	17·7	207	20·7	0·287	20·0
	27	,, (3)	149	21·4	0·336	19·1	155	22·1	0·276	15·6	203	20·7	0·220	15·2
	28	6142	150	20·6	0·325	19·4	121	24·3	0·500	22·6	94	21·4	0·437	19·7
		Mean (*arboreum*)		22·7		21·1		22·0		17·1		20·6		19·3

than the chalazal region. The right side is also seen to exhibit smaller variability than the other two regions as was found with the *hirsutum* cottons.

The extent of variability appears to be greater among the rain-fed cottons than among the irrigated ones.

It will be seen from the foregoing that (1) in most cases, the diameter is greater at the micropylar end, less at the right side and still less at the chalazal end, (2) the coefficient of variation is smaller at the right side than at the other two regions, (3) the variability appears to be greater in the rain-grown *arboreum* cottons than in the irrigated *hirsutum* ones. It, therefore, follows that for comparative purposes the fibres from one region should be examined in all cases. It is suggested that this region should be the right side of the seed on account of the middle value it gives, the smaller

coefficient of variation it possesses and the smaller percentage of immature fibres present in this region as compared with the chalazal end. About 200 fibres from this region would give a fairly accurate value of the uncollapsed diameter. The value obtained by this method, however, may not necessarily be the same as that obtained from a tuft of fibres representative of the whole sample of lint.

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DESIGN OF A SIMPLE QUARTZ MICRO-BALANCE

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(With one text-figure)

RESEARCH workers on textiles are often confronted with the problem of weighing a small mass of fibres as rapidly and accurately as possible. Several types of balances have been designed to give a high degree of accuracy and the object of this note is to describe a quartz balance of the Nernst [1902] type which can be constructed easily and inexpensively, which does not require a telescope and which is capable of giving fairly high accuracy in weighing a small mass. Although the balance has primarily been designed for cotton research, it can be readily used in any type of micro-analytical work.

DESCRIPTION

The balance which is shown in Fig. 1 consists of (1) a tripod stand, (2) a U-shaped brass frame carrying the quartz fibre and a glass capillary beam, and (3) the arm supporting a graduated quadrant.

The tripod stand is mounted on three levelling screws $B_1B_2B_3$, and supports a vertical pillar A_1A_2 having a hole of about 3 cm. depth drilled at its upper end. The cross bar of the U-shaped brass frame $C_1C_2C_3$, which measures about 16 cm. in length passes through the cylindrical rod D, which is slipped into the hole in the pillar and is fixed with the screw E. The upright C_1 can be moved parallel to itself with the help of the screw F. The central pillar A_1A_2 also supports the arm G_1G_2 carrying a graduated quadrant H_1H_2 which is pasted on a mirror J. The quadrant can either be rotated round K_1K_2 or moved horizontally along it or it can be moved up or down by sliding the rod K_1K_2 in the socket G_2. Screws are provided to fix it in any desired position. A plumb line M is provided to level the instrument.

The quartz fibre N has a diameter of about 45-50 microns and is stretched between the two uprights C_1 and C_3. The capillary tube $P_1P_2P_3P_4$ which serves both as the arm and the pointer, having a diameter of 0·5-0·6 mm. is attached to the quartz fibre with the help of a small aluminium piece O which is a special feature of the instrument, and is shown separately in Fig. 1(a). It is made from an aluminium rod measuring about 1·5 cm. in length and having a diameter of about 0·1 cm. and weighing about 50 mg. The middle part of the rod is flattened out by filing, while one end is threaded to take a very small nut R which may be made from brass or preferably aluminium. A narrow slot is cut into the flat portion near the upper end. The capillary tube is provided with a fine needle to serve as a pointer at one end P_4 while at the other end P_1 it is bent into a V to carry the pan Q. It is then bent at right angles twice near the middle, so that the two arms P_1P_2 and P_3P_4 are parallel, their lengths being approximately 15 cm. and 20 cm. respectively, while the vertical part P_2P_3 is only about 0·6 cm. long. The capillary tube is placed in the slot near the upper bend P_2 so that the short vertical part P_2P_3 rests against the flat part of the aluminium piece O and is fixed with a little sealing wax.

CONSTRUCTION AND CALIBRATION

The quartz fibre N is cemented at both ends to the top surfaces of the uprights C_1 and C_3 with sealing wax. It is advisable to use a heated metallic blade with a wooden handle to melt the wax on the uprights, instead of appyling the mild flame directly. In order to fix the capillary tube to the aluminium piece, O the latter is placed across a narrow slit, cut in a metallic or wooden sheet, which is itself held in a horizontal plane by a stand. Holding the capillary tube in position as explained above a drop of molten sealing wax is put on it so as to cement the two rigidly. In order to fix the aluminium piece O (carrying the capillary tube) to the quartz fibre it is best to remove the U piece, $C_1C_2DC_3$, with the quartz fibre attached to it out of the tripod stand and hold it in a retort stand in such a position that the centre of the quartz fibre rests on the flat part of the aluminium piece O just below the capillary bend P_3 and the fibre is fixed to the piece with sealing wax. Afterwards the frame with its attachments is gently removed and placed on the tripod stand A_1A_2 (Fig. 1). The quartz fibre is gently stretched by means of the screw F so that it is taut. A lightpaper pan Q weighing about 10 mg. is suspended from the V bend of the arm P_1P_2, while the other arm P_3P_4 is counterpoised by means of a small quantity of molten wax. The position of the quadrant is adjusted so that the pointer P_4 moves radially over it.

For all these cementing operations it is best to use a hot bar or a microflame.

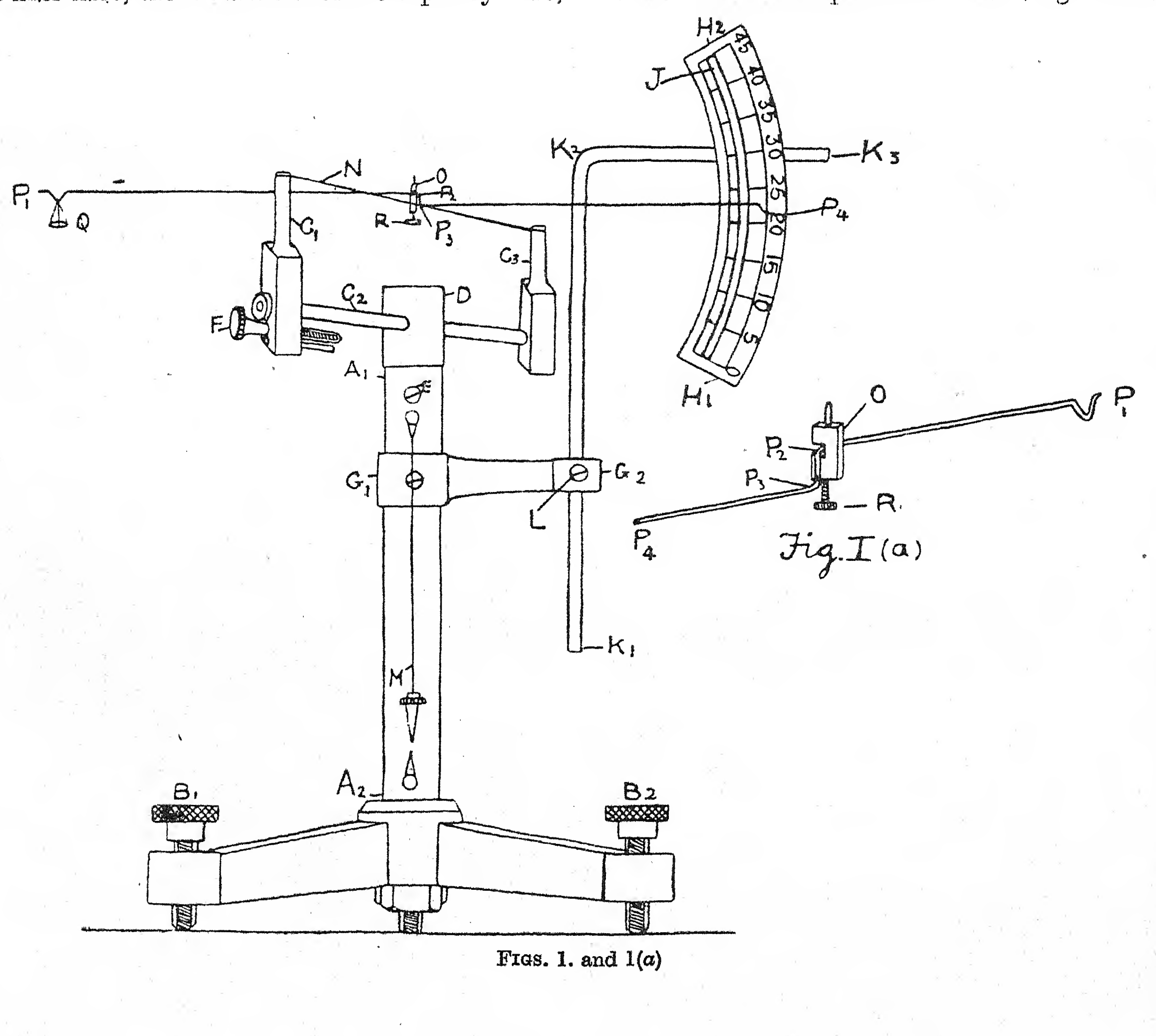
The balance will be found suitable for weighing up to half a milligram with a sensitivity of about 0·0025 mg. If it is required to weigh up to 4 mg. the small nut R weighing about 140 mg., should be gently screwed to the piece O when the sensitivity will be of the order of 0·02 mg. The sensitiveness of a balance of this type can be altered, to some extent, by altering the length of the capillary arm, but in doing so, care must be exercised to see that the fibre does not give way under the combined action of its weight and the tension. It can also be altered to some extent by changing the length of the quartz fibre, but if the fibre is made very long in order to increase the sensitiveness, the balance becomes unsteady owing to constant small vibrations. The sensitiveness can be altered to a very considerable extent by using quartz fibres of different diameters, as the torsional rigidity varies directly as the fourth power of the radius. If it is intended to increase the sensitiveness by using a finer fibre, the dimensions of the capillary tube, the aluminium piece O, etc. will have to be modified suitably so that the fibre can support their weight without snapping.

The balance should be placed on a solid base and enclosed in a suitable case to prevent vibrations due to draught.

Calibration of the balance for the two ranges 0–0·5 mg., and 0–4 mg. is done by using known standard weights. If weights of the intermediate values are not available small pieces of a non-rusting metallic wire of uniform diameter may be used for this purpose. The observed differences may be plotted against the corresponding weights and the graph which should be checked from time to time may be used to read the weight of a small bunch of fibres, etc.

Conclusions

This balance was designed in the first instance for use with the Ahmad-Nanjundayya Stapling Apparatus [Ahmad & Nanjundayya, 1936]. As such the small nut R should be gently screwed on the aluminium piece O as the range of the



FIGS. 1. and 1(*a*)

balance is 0–4 mg. It can also be used for the determination of fibre weight per inch of cotton, and for this purpose the small nut R should be removed so as to increase the sensitiveness to 0–0·5 mg. range. These are, however, only two of the many uses to which a balance of this type may be put. By making small changes in the shape or design of the boat Q used as a receptacle for the object to be weighed, it may be used in any micro-analytical work in which extremely small quantities have to be weighed fairly quickly and accurately. The fact that quartz fibre possesses a high tensile strength and freedom from elastic fatigue, is not affected much by changes in temperature and humidity, and can be drawn out with a uniform diameter confers special advantages on a balance of this type. The time required for the pointer to come to rest in each weighment is found to be of the order of 20–25 sec. It may be possible to reduce this time by using a damping device but as the time is not very large it was thought desirable to aim at simplicity of design and construction. The balance has been tried for some time at the Technological Laboratory of the Indian Central Cotton Committee and has been found to give consistent results in good agreement with those yielded by other sensitive balances. This will be seen from Tables I and II given in the Appendix. Table I shows the results of weighing small tufts of cotton on a torsion balance having a range of 0-5·0 mg. and the balance described in this paper. Table II shows the results obtained for unit fibre-weight of five different cottons with the Quartz Micro-balance ordinarily used in this Laboratory having a range of 0-0·5 mg. [Denham, 1924] and the new balance described in this paper. It will be seen that in both cases the agreement is remarkably good.

It may be useful to indicate roughly the cost of construction of this balance. The cost of construction would depend upon several variable factors, namely, ruling prices of materials, overhead charges, etc. It is estimated that under the present-day conditions the cost of construction would be in the neighbourhood of Rs. 100 only. This should be regarded as a very rough estimate.

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APPENDIX

TABLE I

Results obtained with a Torsion Balance and the New Quartz Micro-Balance (0-4·0 mg.)

Tuft No.	Weight in mg.	
	Torsion Balance	New Quartz Micro-Balance
1	0·97	0·94
2	1·01	1·00
3	1·05	1·05
4	1·26	1·25
5	1·25	1·25
6	1·77	1·82
7	1·93	1·94
8	1·96	1·95
9	2·04	2·01
10	2·49	2·46
11	2·60	2·62
12	2·95	3·01
13	3·05	3·06
14	3·43	3·51
15	3·77	3·71

TABLE II

Results obtained with the New Quartz Micro-Balance and the one, ordinarly used in the Laboratory, (Denham type, 0-0·5 mg.)

Cotton	Unit fibre-weight 10^{-6} gm.	
	Quartz Micro-Balance (Denham type)	New Quartz Micro-Balance
1	2·95	2·86
2	4·05	4·08
3	2·98	2·98
4	3·97	3·88
5	4·73	4·68

A STUDY OF SOIL HETEROGENEITY IN RELATION TO SIZE AND SHAPE OF PLOTS IN WHEAT FIELD AT RAYA (MUTTRA DISTRICT)

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(With three text-figures)

In field experiments, soil heterogeneity is the major factor which contributes towards a very large portion of variation. The work on the uniformity trials done in India and abroad shows that the plot size and shape exercise a considerable influence on the efficiency of the experiment and that usually there is an optimum plot size for a particular crop on a particular soil. In the United Provinces, although field experiments with randomized block and latin square patterns have been conducted since the year 1933-34, no investigation has so far been made to determine optimum size and shape of plots for different crops, the size of plots employed being determined partly on the consideration of convenience of agricultural operations and partly on the knowledge of the results of the uniformity trials conducted elsewhere. The need for finding out a suitable plot size for various crops in the United Provinces has, therefore, long been felt. This paper deals with the results of the uniformity trials on wheat, conducted at Government Research Farm, Raya (Muttra District), during the *rabi* season of 1939-40.

Literature

A catalogue of uniformity trials has been recorded by Cochran [1937] and reviewed by Fairfield Smith [1938]. In India studies on the experimental errors in relation to size and shape of plots have been conducted on sugarcane by Sayer *et al.* [1936], Bose *et al.* [1939] and Vagholkar *et al.* [1940]; on cotton by Hutchinson and Panse [1935] and Panse [1941]; on rice by Bose *et al.* [1936]; and on wheat by Krishna Iyer [1942].

Procedure

The general method of studying the problem consists of dividing the field in small plots and calculating standard errors for plots of different size and shape by combinations. To eliminate the effect of soil heterogeneity, some workers have superimposed randomized block layout, while others have used latin square layout. The efficiency of the layout for a particular area depends upon the type of soil heterogeneity existing in the field and the method by which it is eliminated. In the present paper soil heterogeneity has been eliminated by three methods, (*i*) between the rows, (*ii*) between the columns, and (*iii*) between adjacent lots, and attempts have been made to study the intrinsic relation between the residual variation and the size and shape of plots. The first two methods of eliminating soil heterogeneity are similar to those of a latin square. The third method was first suggested by Papadakis [1937] and has been employed by Bartlett [1938] in recovering information from replicated field experiments with large blocks. The method consists of calculating fertility index for each plot as the mean of the four plots all round it. Taking the actual yield as y and the mean of the four plots as x, analysis of co-variance is worked out as usual. In the case of edge and corner plots, the means of three and two contiguous plots respectively were taken as the values of x. These three methods have been applied to the data from the uniformity trial of wheat C 13 with a view to study soil heterogeneity in relation to size and shape of plots for field experiments on wheat at Raya.

Material

The trial was laid out in 1939-40 *rabi* at the Research Farm, Raya, which represents the soil and climatic conditions obtaining in the western U. P. Wheat C 13 variety was sown over an area of 180 ft. × 243 ft. with 324 rows on a field of average fertility. It had wheat during 1938-39 *rabi* and was fallow during 1939-40 *kharif*. The seed was sown behind *desi* plough in rows 9 in. apart, the length of each row being 180 ft. The crop was irrigated twice during the season and other usual operations were carried out according to the practice at the farm. At the time of harvest 18 rows on both sides and 10 ft. at the end of the field were discarded to eliminate border effects and an area of 160 ft. × 216 ft. with 288 rows was harvested in small units, each being 2 ft. 3 in. broad with three rows 20 ft. long. Thus there were 96 units across the rows and eight units along the rows. The total number of unit plots thus obtained was 768. The yield of grain for each unit plot was weighed and recorded separately and is given in the appendix.

Statistical analysis

The 768 units of plots were grouped to give plots of 3 rows, 6 rows, 9 rows, 12 rows, 18 rows, 24 rows, and 36 rows wide and 20 ft., 40 ft. and

80 ft. long. The side along the wheat rows was treated as length and that across the rows as breadth irrespective of magnitude. The data was analysed by Fisher's analysis of variance. Systematic soil variation along the rows and columns was eliminated and standard errors for plots of different size and shape were calculated from the residual mean square. The results are given in Table I (*a*).

TABLE I

Standard error per plot in per cent of the mean for plots of different size and shape

Length	Breadth						
	2 ft. 3 in. (3 rows)	4 ft. 6 in. (6 rows)	6 ft. 9 in. (9 rows)	9 ft. (12 rows)	13 ft. 6 in. (18 rows)	18 ft. (24 rows)	27 ft (36 rows)
(a) Before eliminating variation due to correlation between adjacent plots							
20 ft. . .	21·8	17·8	15·2	14·0	11·9	10·2	8·6
40 ft. . .	19·5	16·0	13·6	12·4	11·1	8·9	7·8
80 ft. . .	18·7	15·6	13·6	12·0	11·0	8·7	7·2
(b) After eliminating variation due to correlation between adjacent plots							
20 ft. . .	12·4	11·1	9·9	9·0	7·9	6·7	5·8
40 ft. . .	11·6	10·5	8·7	7·8	6·7	5·7	5·2
80 ft. . .	11·4	9·4	7·6	6·8	5·4	4·4	2·6

The standard error is highest for the smallest plot (2 ft. 3 in. × 20 ft.) and decreases gradually when both the length and breadth of the plot are increased. Table I (*b*) shows the standard errors for plots of different size and shape after further eliminating variations due to correlation of adjacent plots by Papadakis' method. There is an appreciable reduction in the standard errors due to adjustment by the fertility indices for all plot sizes. Comparing the standard errors for plots of different size, it is seen that errors decrease with increased plot size. Fig. 1 shows the relation between the average standard error and the plot size.

When the plot size is increased from 45 to 270 sq. ft. there is a steep fall in the standard error but by further increase beyond 360 sq. ft., the fall becomes gradual. This shows that the plot size for field experiments with wheat should be between 270 and 360 sq. ft. Iyer [1942] while studying the data of uniformity trial on wheat at Karnal has found 400 sq. ft. as the optimum size of plot for field experiments with wheat. Comparing standard errors for plots of different shape [Table I (*a*) and (*b*)] it is observed that long, narrow plots are not less variable than broad plots of the same size. This finding differs from those of other workers.

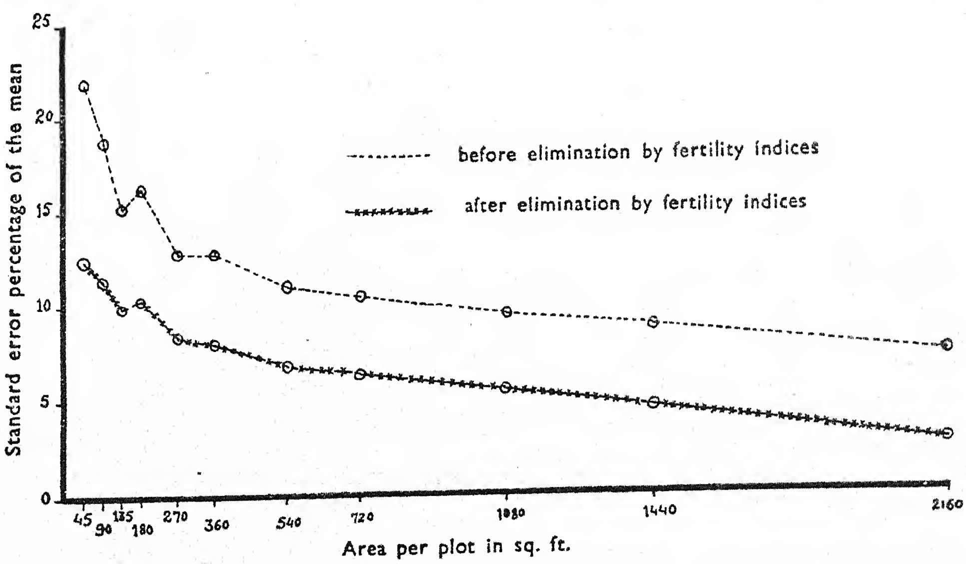

FIG. 1 Variability in relation to size of plots

Table II shows the percentage efficiencies (100 × variance before adjustment/variance after adjustment) of adjustment by the fertility indices for plots of different size. It is interesting to note that efficiency is above 200 for all plot sizes. This shows that Papadaki's method is useful in further reducing error variance and thus increasing the precision of the experiment. According to Papadakis [1937] the reduction in the error is most marked when the plots are long and narrow. This is corroborated by the data presented in Table II.

TABLE II

Percentage efficiencies of adjustment by the fertility indices for plots of different size and shape

Length	Breadth						
	2 ft. 3 in.	4 ft. 6 in.	6 ft. 9 in.	9 ft.	13 ft. 6 in.	18 ft.	27 ft.
20 ft. . .	310	262	238	241	224	234	218
40 ft. . .	281	232	246	254	272	242	223
80 ft. . .	270	275	319	308	418	390	754

Fig. 2 shows the relation between average efficiency and plot size. When the plot size is increased from 45 to 135 sq. ft., the efficiency falls rapidly. From 135 to 270 sq. ft. it is practically the same, but by further increasing the plot size beyond 270 sq. ft., the efficiency rapidly rises. This implies that while Papadakis' method is efficient for designs with plot size of 45 sq. ft., it is still more efficient for plots of 1080 sq. ft. and above.

DISCUSSION AND CONCLUSION

A study of standard errors from the residual variance, after variation due to all known components are eliminated, for plots of different size and shape is useful in determining the optimum size and shape of plots for field experiments. In the present case three components of soil heterogeneity have been eliminated, (*i*) rows, (*ii*) columns, and (*iii*) correlation between adjacent plots.

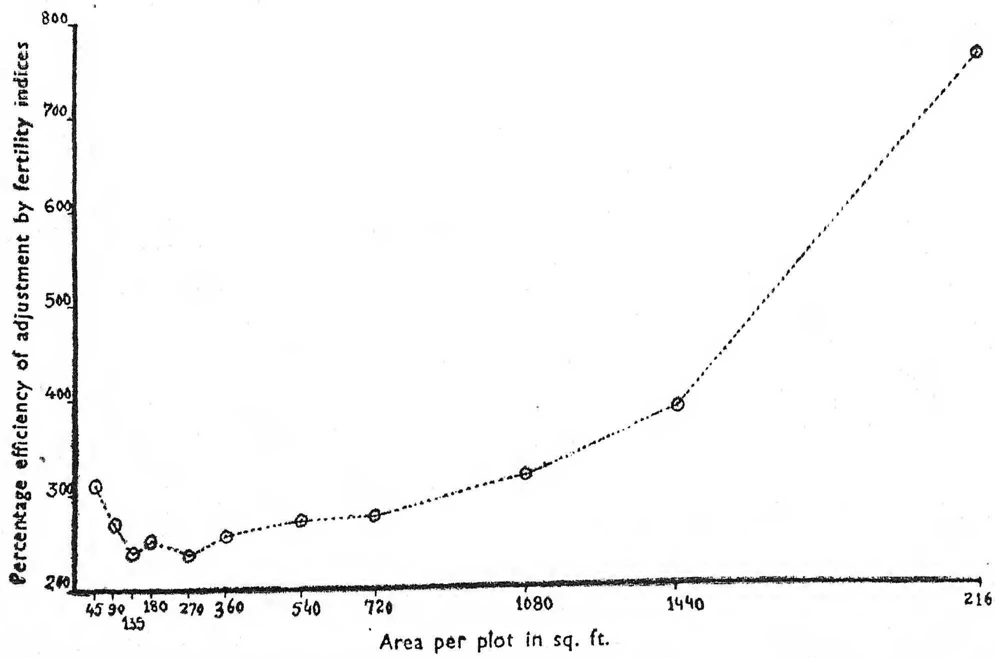

FIG. 2 Average percentage efficiencies of adjustment by fertility indices for plots of different size

While rows represented on an average only 2 per cent variation, columns represented 80 per cent of the total variation. Adjustment by the fertility indices has further eliminated variation of 10 per cent. Thus a very large portion of soil heterogeneity was observed between columns. The contour fertility map (Fig. 3) shows that there are stripes of high and low fertility along the wheat rows. History of the field reveals no explanation for this phenomenon, as an average field usually found on the farm was selected for the trial.

From the study of standard errors it is observed that the relative variability is diminished as the plot size is increased. This shows the intrinsic relation between variability and plot size after all known sources of variation are removed; but since the area is limited the increase in plot size results in the reduction in the number of replications which increases the variability. In order to find out the relative efficiency of a plot size corrected for the number of replications it is necessary to take both the plot size and number of replications into consideration. This is done by calculating the relative efficiency of the plot size as shown by Sayer *et al.* [1936] and is obtained by multiplying the variance per plot by the number of ultimate units, contributing to the total of that plot and taking the reciprocal.

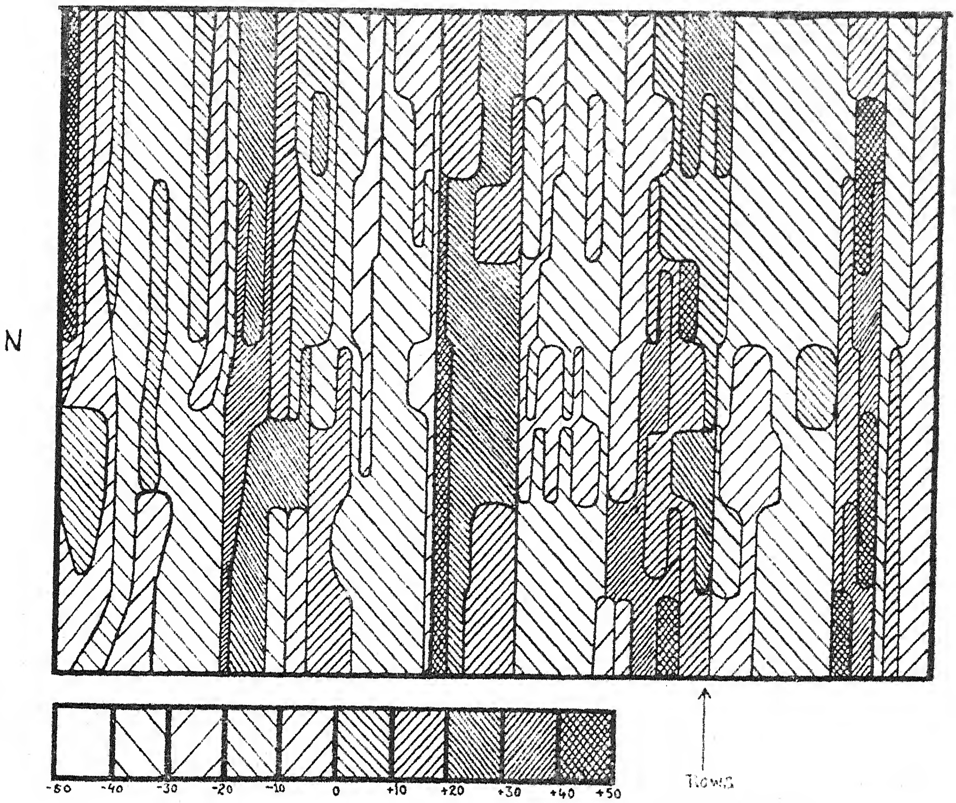

FIG. 3 Fertility contour map from data of wheat uniformity trial at Raya

Taking the efficiency of the smallest plot as 100, the efficiencies of other plots are calculated. This is shown in Table III.

TABLE III

Relative efficiencies for plots of different size and shape

Length	Breadth						
	2 ft. 3 in.	4 ft. 6 in.	6 ft. 9 in.	9 ft.	13 ft. 6 in.	18 ft.	27 ft.
Before eliminating variation due to correlation between adjacent plots							
20 ft. . .	100	75	69	61	57	57	54
40 ft. . .	63	47	43	39	33	38	33
80 ft. . .	34	24	22	21	17	20	19
After eliminating variation due to correlation between adjacent plots							
20 ft. . .	100	63	53	48	41	43	38
40 ft. . .	57	35	34	32	29	29	24
80 ft. . .	30	22	22	21	22	25	47

It is seen that the smallest plot (20 ft. × 2 ft. 3 in.) is the most efficient and efficiency rapidly decreases as the plot size is increased. Here too, long plots are not more efficient than the broad plots of the same size. The rapid fall of efficiency with increased plot size suggests that the plot size should be as small as could be managed conveniently. In other words, efficiency could be better attained by increasing the number of replications. From a study of the relative variability and efficiency, a plot size of 270 sq. ft. seems to be optimum for varietal trials at the farm. For agronomic trials it may be increased to 360 sq. ft. if necessary for convenience of agricultural operations. In progeny row trials for breeding of new strains, due to limited quantity of seed, the plot size has necessarily to be small and efficiency could be attained after allowing sufficient number of replications.

The relation between efficiency of adjustment by fertility indices and the plot size is interesting. While a high correlation between adjacent plots was observed for plot of the smallest size, a still higher correlation was noticed for plots of the biggest size. This shows that Papadakis' method is more efficient for designs with small plot size or

with very big plot size. This finding is of great use in further reducing the experimental error and thereby increasing the precision of the field experiments. At this place, however, it is necessary to point out the theoretical limitations of Papadakis' method arising by the double use of each plot yield for x and y in the analysis of covariance. Bartlett [1938] investigated the applicability of this method from theoretical point of view and concluded that where the number of plots per block is large, the method should be approximately valid. The results obtained by Papadakis' method in the present investigation are, however, subject to this limitation.

Summary

The data of uniformity trial with wheat C 13 conducted during 1939-40 *rabi* at the Cotton Research Farm, Raya, was studied with a view to determine optimum size and shape of plots for field experiments with wheat. The utility of Papadakis' method of adjustment by the fertility indices was also investigated in relation to plots of different size. The following conclusions are drawn :

(1) Considering the standard errors and relative efficiencies, a plot size of 270 sq. ft. has been found to be optimum for wheat varietal trials. This may be increased up to 360 sq. ft. for agronomical trials, if necessary. For progeny row trials, efficiency of the small plots could be maintained after allowing sufficient replications.

(2) Long plots have no advantage over broad plots of the same size.

(3) Papadakis' method was found to be useful in further increasing the efficiency, particularly for plots of very small size and of very big size. The limitations to the applicability of this method have been pointed out.

Acknowledgement

The authors are grateful to Mr K. Kishen, Statistician, Department of Agriculture, United Provinces, and Dr V. G. Panse, Statistician, Institute of Plant Industry, Indore, for having taken the trouble of going through the manuscript and giving some very useful suggestions. Our thanks are also due to Mr K. Nain Kausal, for the laborious computation involved in this investigation and for the preparation of the text-figures.

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APPENDIX

Uniformity trial with wheat C13 at the Government Research Farm at Raya (District Muttra) during 1939-40 Rabi

(Yield of grain per plot—unit ½ oz.)

60	60	58	39	37	45	27	34	25	41	47	28	40	30	57	49	39	30	29	70	52	68	61	38
78	68	48	40	31	46	27	26	29	32	37	28	33	30	52	43	40	32	32	72	70	48	66	39
94	54	37	48	40	48	26	28	33	28	53	32	34	24	58	50	38	35	34	78	76	70	79	44
77	55	43	40	41	49	33	30	36	27	40	33	34	34	60	49	41	37	33	82	73	66	78	40
55	33	34	43	35	35	26	24	35	45	30	38	34	31	41	37	43	31	70	84	82	84	94	34
46	33	49	45	46	34	27	33	30	46	28	36	26	34	46	32	34	30	88	101	78	69	81	40
68	38	51	43	37	41	25	26	36	40	32	41	29	33	48	38	35	38	82	86	69	64	78	38
37	18	41	31	31	53	41	39	43	44	33	30	34	30	32	25	23	13	82	70	72	44	73	25
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

33	48	52	48	48	37	36	30	31	20	32	35	40	34	43	45	33	50	64	42	50	67	72	38
40	42	48	67	46	32	43	26	30	20	26	34	34	35	36	38	16	64	56	40	41	50	76	40
41	46	35	45	43	29	30	23	24	24	28	28	33	36	43	26	16	90	75	64	70	61	50	48
43	54	60	52	45	30	31	24	31	29	38	32	46	35	34	28	19	84	63	73	57	72	51	66
38	51	67	29	52	20	40	25	23	40	32	38	30	22	37	23	17	90	89	64	67	71	68	47
60	66	64	40	52	29	36	28	21	32	31	31	31	35	40	33	23	77	87	76	60	73	54	72
36	46	59	39	44	39	28	28	32	36	40	35	30	28	25	26	21	80	66	77	70	61	52	58
32	44	52	42	57	40	38	42	26	49	32	37	21	25	32	25	12	76	86	72	60	59	52	40
25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

68	72	40	39	38	44	24	28	40	33	32	28	30	41	34	39	53	49	45	43	76	55	50	56
80	58	32	30	40	34	30	25	27	35	35	23	28	36	38	38	44	36	42	48	73	64	51	65
54	44	21	32	39	28	23	40	32	33	48	20	25	43	36	35	61	43	46	50	57	51	52	49
67	67	35	39	51	33	24	40	29	24	40	23	31	43	43	38	62	72	59	65	78	94	41	42
52	62	42	28	41	38	37	32	40	34	32	18	41	35	46	78	75	66	55	56	63	57	48	42
66	47	26	35	33	38	29	31	40	37	37	20	40	43	42	76	60	61	53	65	66	68	66	56
58	52	28	33	44	29	25	29	32	25	29	26	46	76	58	76	54	54	60	74	46	48	73	64
59	46	29	28	30	39	26	25	30	29	29	12	26	44	37	81	74	75	87	90	58	48	62	60
49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72

74	26	31	38	38	33	32	34	34	26	22	22	31	35	45	55	32	57	31	40	28	42	37	45
60	24	30	44	38	33	36	35	40	26	28	31	27	36	43	44	71	90	24	46	33	44	34	38
46	24	28	24	33	33	33	30	36	24	30	35	32	33	69	53	86	82	30	43	32	34	36	49
56	26	25	29	24	46	44	37	32	24	33	28	32	40	63	60	73	81	30	36	32	40	40	44
30	30	36	37	38	36	30	33	24	54	50	48	46	48	58	73	54	76	31	46	40	38	43	47
27	35	39	28	36	36	40	46	34	42	34	30	33	34	55	66	58	91	34	56	41	44	38	42
30	29	23	33	40	31	24	28	26	47	26	34	32	33	64	82	50	84	35	55	29	36	24	39
38	41	40	36	39	32	38	31	24	32	40	32	37	36	86	111	78	72	36	65	38	44	37	46
73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96

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SELECTED ARTICLE

SOME RESULTS OF STUDIES ON THE DESERT LOCUST (*SCHISTOCERCA GREGARIA* FORSK.) IN INDIA*

By Y. Ramchandra Rao, M.A., F.R.E.S., F.I.Ac.Sc., Late Locust Research Entomologist, Imperial Council of Agricultural Research, India

[A voluminous general report on the organization and the results of the locust investigations carried out in India in 1931-1938, under the auspices of the Imperial Council of Agricultural Research, was officially submitted to the Council by Rao Bahadur Y. Ramchandra Rao in 1941, but its publication has been postponed until after the war.

A copy of the report has been sent, by permission of the Council, to the Anti-Locust Research Centre at the Imperial Institute of Entomology, for information, and it proved to contain a wealth of data and of ideas, only some of which have been published in various preliminary papers by its author and by his colleagues. In view of the great scientific and practical value of the report, it appeared necessary to make at least its main findings available to other entomologists working on the subject, and permission has been obtained from the author and from the Imperial Council of Agricultural Research for the publication of some sections of the report. Only a few sections, selected and edited by Dr B. P. Uvarov, are being published below, and it should be stressed that their publication in the abridged form does not in any way detract from the value of the complete report, which, it is hoped, will be published at the earliest opportunity for the benefit of all workers on the locust problem.]

Studies on the development

Maximum number of successive generations possible in a year

Husain and Ahmad [1936] have proved that there is no diapause in the Desert Locust, *Schistocerca gregaria* Forsk., in any stage of its development and that as many as eight successive generations may be obtained within a year at a constant temperature of 40°C., about seven generations at 36°C., and five at 30°C. Under natural conditions, however, there is always a considerable fluctuation of temperatures, diurnal as well as seasonal, so that the duration of a brood would naturally vary in accordance with the prevailing temperatures. In nature, the main factor in the breeding of the locust would appear to be the presence of an optimum amount of moisture in the soil. This, under natural conditions, is dependent on requisite rainfall, and as apparently the mass-multiplication of the locust depends on optimum conditions of rainfall, it was considered desirable to measure the potentialities of increase possessed by the insect by rearing it under confinement in cages in the actual desert environment, but providing it with the optimum amount of soil-moisture. Pairs of locusts kept in cages and provided with fresh food and with wet sand at the bottom were found breeding satisfactorily and producing a succession of generations, although in nature in the neighbouring breeding grounds, only a single generation was observable.

The results of breeding permit the following deductions to be made :

1. During late spring and in summer, when the average monthly mean temperatures vary from 28 to 30°C., the periods of sex maturation, egg incubation and hopper development are shortest, but in spring and autumn, when the means range from about 22 to 26°C., they tend to be much longer, and in winter development is extremely slow. In summer, sex maturation may occur in 3 to 4 weeks, eggs may hatch in about 14 days and hopper development may be completed in about 31 days.

2. In mid-summer, the life-cycle, from oviposition by the parent generation to egg-laying by the progeny, may be completed in about two months and a half, but since it is much longer in spring, autumn and winter, it is not possible to have more than three successive generations during the year. At Pasni the total time taken for the four successive broods was about 14 months. At the utmost, one might have seven generations in the course of two years.

3. At Pasni, there is usually only one brood in the year in the spring months, and as summer is a period of drought, there is no breeding then. On the other hand, Ambagh and Chachro fall within the zone of summer rainfall and breeding occurs only in summer, and there is no breeding in winter and spring, which are periods of drought. Usually, locusts tend to leave areas of drought and migrate elsewhere. However, whenever there is good rainfall in summer at Pasni breeding may take

*Reprinted from the Bulletin of Entomological Research, Vol. 33, Part 3, December, 1942

place there. Moreover, in years of heavy rainfall young hoppers were being met with at Pasni in certain special areas from June to September, although none were noticed on the general *rek*, (sand dune) areas after May. On investigation, this was found to be due to egg-laying in wet patches of sand laid bare by the heavy south-west wind. This would indicate that breeding may, under these special conditions, continue in these areas in spite of the absence of rainfall. Similarly at Ambagh, light breeding was noted in spring in 1939 as a result of exceptionally heavy rainfall, though usually no breeding occurs there in spring.

4. Although there is usually little possibility of there being more than a single generation at places like Pasni and Ambagh in an ordinary year, the powers of migration possessed by locusts enable them to reach places where they may be able to lay eggs immediately. New adults emerging in April on the coastal *reks* may reach the interior valleys of Mekran and start a new brood in May, and adults of this new generation appearing by the end of June, may migrate to the Rajputana desert in July and may lay eggs during the month. Adults of this generation appearing in September may, under favourable circumstances, start a new brood by the end of the month. Theoretically, therefore, there is the possibility of four successive generations following one another in the course of the year, though ordinarily not more than three broods can be expected.

The length of the incubation period under semi-natural conditions correlated with soil temperature

Eggs are deposited in fairly soft sandy or loamy soils, generally at a depth of about 4 in., and their development is dependent on the existence of optimum conditions of soil-moisture and soil temperature at that depth. Under natural conditions in the desert, the requisite moisture conditions are obtainable only for 3 to 4 weeks after good rainfall, and usually the locust lays its eggs only when the soil-moisture conditions are satisfactory. On the other hand, conditions of soil temperature are affected not only by the diurnal and seasonal fluctuations of atmospheric temperatures, but also by the intensity of solar radiation.

In the course of breeding experiments undertaken at Pasni, the actual times of egg-laying and hatching were noted in a large number of cases and correlated with the average mean temperature of moist sandy soil at 4 in. depth observed in cages during the development. Although the correlations cannot be claimed to be accurate, the results (Table I) may give an approximate idea of the length of the incubation period that may be expected under particular types of seasonal conditions in nature.

TABLE I

Incubation period in relation to soil temperature at 4 in. depth, showing the difference in values for each rise of a degree Centigrade. Compiled from data for the years 1932 to 1937

No. of records	Soil temperature of moist sand at 4 in. depth °C.	Incubation period in days	
		Individual records	Averages
2	19	73, 70	71·5
1	20	48	48
1	21	37	37
6	22	37, 36, 34, 36, 32, 29	34
3	23	28, 29, 29·5	28·8
7	24	27, 27, 26, 29·5, 27, 25, 27	26·9
3	25	25, 24, 25	24·7
11	26	25, 25, 24, 22, 26, 26, 25, 22, 23, 28, 25	24·6
19	27	23, 20, 21, 23, 21, 20, 23, 25, 22, 23, 24, 24, 21, 24, 20, 21, 20, 20, 20	21·8
9	28	18, 19, 22, 22, 19, 19, 19, 18, 19	19·4
11	29	20, 19, 19, 16, 17, 18, 17, 18, 19, 18, 19	18·2
12	30	16·5, 14·5, 14, 17, 17, 17, 17, 16, 17, 17, 17, 16	16·3
24	31	16, 15·5, 15, 14, 16, 16, 13, 16, 15, 18, 15, 16, 16, 17, 16, 14, 17, 16, 14, 15, 14, 15, 14, 15	15·4
13	32	15, 15, 15, 16, 13, 15, 15, 14, 15, 15, 15, 14, 14	14·7
14	33	16, 15, 14, 14, 16, 14, 14, 12, 14, 15, 15, 14, 14, 15	14·4
1	34	13	13

The length of the post-embryonic period under semi-natural conditions, correlated with average atmospheric temperatures

Table II shows the correlation between the average daily mean temperature and the length of the hopper period.

The results show that the shortest period recorded is 32 days at an average mean of 31°C., while at an average of 20°C., the duration is as high as 85 days.

Food and sexual maturation

Bodenheimer [1932] made the suggestion that fresh succulent vegetation growing after rainfall may exert a powerful influence in quickening the sex maturation of locusts. In order to test this, Dr K. R. Karandikar confined pairs of locusts of known age in oviposition cages and fed them on fresh shoots of marrand (*Heliotropium undulatum*). Although the sand at the bottom of the cages had been kept quite dry, the locusts attained maturity in about two months and dropped their eggs on

the surface of dry sand. At that season, there was no fresh marrand anywhere on the Pasni *reks* on account of the drought nor were any mature locusts met with in the area.

TABLE II

The correlation between the length of the post embryonic period and mean atmospheric temperature. Compiled from data of 1933-35

Temperature °C	Minimum duration of post-embryonic development (in days)			
	1933	1934	1935	Averages
20°	...	85	...	85
21°	83	...	...	83
22°	...	...	...	...
23°	...	54	...	54
24°	44	54	...	49
25°	41, 40	...	43, 42, 39, 37	40
26°	35, 36	...	36	36
27°	34, 36	39	...	36
28°	...	...	37	37
29°	...	...	38	38
30°	34	36, 34, 34	...	34
31°	32	...	...	32

TABLE III

Effects of food on sexual maturation

Plant	Yellowing of wings in days	First oviposition in days	Number of egg-pods
Eliotropium undulatum, fresh	13—25	33—79	2—4·4
Ditto, old	17—25	43—90	0—3
Jowari (Sorghum)	13—36	28—72	2—5
Ditto, seedlings	7—20	25—37	3—5·3
Maize	13—16	34—64	1·7—3·7
Sericostoma pauciflorum, fresh	12—25	33—76	1—4
Ditto, old	13—16	39—67	1—3
Aerua tomentosa	15—41	37—104	0—4
Cyperus arenarius	21—68	38—100	0—2
Mixed plants	21	57	1·8
Cabbage	8	24	6
Indigofera cordifolia	17	37	1
Tribulus terrestris	11	36	2

On the basis of these results, further experiments were undertaken. These experiments included (1) the use of fresh shoots of marrand as against shoots of old or semi-dry marrand, (2) old marrand shoots wetted to counter-balance the deficiency of water-content, (3) old marrand kept in a moist atmosphere, and (4) fresh shoots of other food-plants. Subsequent experiments were restricted to comparative tests of fresh and old marrand, of fresh and old kharzan (*Sericostoma pauciflorum*) and to tests of other important food-plants. In all these experiments, the appearance of the yellow tinge of the hind wings has been taken as the first landmark in sex maturation, though the final criterion, of course, would be the date of first oviposition.

The results given in Table III are averages, and the differences do not, for that reason, appear in many cases to be very striking, but they are markedly significant, e.g. in the case of short duration of sex maturation on sorghum, maize and cabbage.

The circumstance that cereal crops like sorghum and maize have been found to hasten the sex maturation of adult locusts is of significance owing to the fact that in all known cases of outbreak centres found in the various parts of Mekran and Lasbela, sorghum crops are associated with their formation. Not only have the hoppers been found on and among such crops, but adult locusts have been observed concentrating in them for feeding and resting. Similarly, in the Sind-Rajputana desert areas, where *bajri* (*Pennisetum typhoideum*) is the chief cereal crop, hoppers as well as adult locusts have been found congregating among the crops. In the absence of cultivation, wild plants like marrand, kharzan, *Indigofera cordifolia* and *Tribulus*, all of which are preferred food-plants, proved by these experiments to have a stimulating effect on the maturation of the locust, may similarly induce outbreak centres to form in those places where they occur in masses.

Food and the rapidity of growth of hoppers

Freshly hatched hoppers were reared individually and in batches on different wild and cultivated food-plants.

The results showed that the food-plants experimented with may be placed in the following order in regard to their effect on the developmental period of hoppers during the hotter months :

Kolhrabi cabbage (31 days) ; sorghum seedlings (35·9) ; *Indigofera cordifolia* (36) ; *Tribulus terrestris* (37) ; *Convolvulus pleuricollis* (38·7) ; fresh *Heliotropium undulatum* (40) ; fresh *Sericostoma pauciflorum* (40) ; maize seedlings (44) ; *Crotalaria burhia* (44·5) ; *Aerua javanica* (45·6).

General observations on food and development

Although the experiments carried out were not exhaustive, they have given fairly definite indications as to the importance of the quality of food in causing an acceleration of the sexual maturation of young adults and of the growth of the hoppers

Since it is now generally conceded that the development of an outbreak centre is almost always due to the rapid development of two generations in quick succession, any factor that might contribute to the speeding up of the breeding would be of the utmost importance in this connection, and there is little doubt that the presence of food-plants capable of stimulating the rapid growth of hoppers and of hastening the maturity of young adults would play an important part in the causation of incipient swarming.

Kennedy [1939] was not inclined to allocate to the food factor anything but a subsidiary role. While conceding that growth-stimulating foods such as *Heliotropium undulatum* might accelerate 'Real Concentration', since the more mobile later instars would thereby be reached sooner, and also that growth stimulation might assist in 'Virtual Concentration' as a result of rapid breeding, he believed that this would only contribute to the fitting in of a second generation into a winter season. He further said (p. 444) that the effect of food on the rate of sexual maturation can only influence prospects of a second winter generation and hence of 'Virtual Concentration', but would have no influence on concentration of the first winter generation.

In the Mekran area of the Indian region, where spring breeding usually occurs, locusts are found over-wintering in the coastal areas and the earliest breeding also occurs there. As the spring advances, locusts migrate into the interior valleys of Mekran from the coast and may breed there if conditions are favourable during the months of April, May and June. Adults of the new generation begin to appear on the coastal areas early in April and usually migrate into the hinterland more or less immediately. As the interior of Mekran is mostly hilly and stony and patches of natural vegetation as well as of cultivation are restricted to loamy soils at the bottom of the valleys, migrating locusts usually become concentrated on such patches (Real Concentration). Summer cultivation there is mostly confined to the sorghum crop, and various wild plants, such as species of *Astragalus*, *Trigonella*, *Tephrosia*, *Tribulus*, *Chrozophora* and *Heliotropium*, as well as the Camel-thorn, *Alhagi camelorum*, all of which are plants relished by locust adults and hoppers, are generally commonly found near cultivation. Locusts concentrated on the sorghum crop may be expected to attain sexual maturity very early and to lay eggs in the neighbourhood, and the hoppers on hatching would find a fair amount of growth-stimulating food. As temperatures in the late spring are fairly high, breeding would be rapid and conditions should apparently be quite favourable for the development of incipient swarms. Although no actual observations have been made on this point, several outbreak centres are known to have developed under such conditions in the interior of Mekran.

As to the adults of the over-wintered brood, it is now fairly well established that the locusts found in the winter months in the Mekran coastal areas are mostly migrants from summer brood areas in the Sind-Rajputana desert. On the coastal *reks* the vegetation is generally very much dried up at the end of autumn, but with the setting in of the moist western winds at the end of autumn, most of the perennial vegetation on the *reks*, such as *Heliotropium undulatum* and *Sphaerocoma aucheri* put forth fresh shoots in spite of the absence of rainfall, and tender shoots may be expected to stimulate sexual maturation even before the occurrence of the winter rains. On the other hand, with the commencement of rainfall, various annuals spring up on the *reks* and furnish food capable of quickening sex maturity among the over-wintered adults, though there is not much likelihood of any concentration being caused under the conditions prevalent at this period on the coastal areas.

In addition to the natural vegetation, young crops, such as wheat, barley and rape, raised in parts of Mekran would also provide food capable of stimulating maturity, in case locusts happen to be present in the neighbourhood.

Effect of sunlight on the coloration of wings

In recently fledged adult locusts, the hind-wings are always hyaline. In cold weather there may be no development of colour for a long time, but in summer a tinge of yellow usually makes its appearance within a week, signifying the onset of sex maturation and the deepening of yellow colour is a positive indication that the insect is mature.

In many specimens of locusts collected from nature, the occurrence of pink or mauve or light blue colour at the base of the wings was often noticed. During the earlier years of the locust survey work the significance of this coloration was not recognized. It was not till the year 1935, when definite proof of the migration of solitaires was first obtained, that the significance of the possession of distinct mauve or pink patches on the wings in connection with migration was first noted. Observations repeated during the summer and autumn migrations of 1936 and 1937 clearly showed that such a pink or mauve tinge in the wings was, decidedly connected with active migration flight being presumably the effect of the action of solar radiation on the wings, while exposed to the sun during flight. With the object of obtaining a confirmation of this conjecture, some experiments were devised.

A cage was set up in which some recently transformed locusts were introduced after having one, or both, elytra removed. The cage was kept in the open, fully exposed to the sun, which was very bright and hot. In the course of a week or two, wings exposed to the sun had in all cases acquired a pink colour, which subsequently gradually deepend into mauve. In the case of specimens, in which only the right elytra had been removed, it was noticed that pink or mauve had appeared even in the left wing, although the colour was less intense.

In other experiments, Mr R. N. Batra removed the right elytron and painted the other elytron black so as to prevent the sun's rays from infiltrating to the wing beneath, and found no trace of pink or mauve developing on them even at the end of a month, though there was colour development as usual on the exposed wing. When he painted both elytra black, the development of mauve or as pink had been completely eliminated. When right forewings removed, with both elytra removed and with both elytra intact, were kept in boxes locusts, with the completely shut off from sunlight neither pink nor mauve made its appearance, though the yellow tinge characteristic of the onset of sex-maturity developed in due course.

These experiments indicate that the appearance of light mauve or pink in wings, even in those cases where the forewings had not been removed, should have been due to the infiltration of sunlight through the fore-wings.

On the whole, the experiments have fairly clearly proved that the development of pink, mauve or light blue at the base of the hind-wings is the result of exposure to sunlight. In nature, there is a great amount of variation in the type of colour, as well as in the depth of the tinge. Pink is common in the gregarious forms, and in 1935 many of the immigrants showed a pink colour not only on the hind-wings but also on their bodies. On the other hand, mauve is very common among the autumn migrants found in the Lasbela and Mekran areas during the months October to December. In some cases there is only a very light pale bluish suffusion at the base of the wing, and in other the mauve is well developed. In certain cases only the veins acquire a dark bluish colour, while there is no colour at the base. All these differences are probably due to the degree to which the wings have been exposed to sunlight during flight. In the summer months it is probable that migration takes place in the evening or early part of the night while in the autumn months and in winter the nights are cold and movements probably occur during midday or early afternoon. In the latter case there are greater chances of exposure to sunlight and at this time, moreover, locusts love to bask in the sun, hence the deep mauve of the wing-bases and also the darker body colour. Since pink is associated to a greater extent with the *gregaria* forms and mauve tinge with the *solitaria* individuals, an investigation into the physiology of these colour developments may throw much light on their relationship with phase.

Biometrical Studies

Biometrical ratios

The ratio E/F (elytron length over hind femur length) was the one almost exclusively adopted for studying the populations found in different areas. In view of the frequent cases where the tips of the elytra were broken, it was necessary to evolve a method of estimating their length. After various tests, the point where the anal (or vannal) area ends on the posterior margin of the elytron was found the most suitable for determining the position of the specimen on the E/F scale, since the length of the elytron up to the tip of the anal area was found to bear a definite relation to the length of the entire fore-wing. It is proposed to call this point the 'Vannal Apex' or 'Vannal Tip,' and the new ratio, which is determined in exactly the same manner as the E/F ratio, the V/F ratio.

Since the E/F and the V/F ratios are both based on the length of femur (F), the relationship between the two ratios is the function of E/V. By numerous measurements it was found that the function varies between $1\cdot30$ to $1\cdot33$ on the whole, and in the majority of cases it is between $1\cdot31$ and $1\cdot32$. If the V/F ratio is determined, E/F ratio would probably lie between $V/F\times1\cdot31$ and $V/F\times1\cdot32$.

In the course of making measurements of the various parts of the locust for the determination of the pronotal ratios, it was apparent that the width of the head was a fairly significant point for examination. A comparison of the heads of specimens of the phases *solitaria* and *gregaria* showed that while there were clear differences in width at the genal region of the face, there were none in the region of the compound eyes. Comparing the facial contours of *solitaria* and *gregaria*, a distinct bulge is seen in the cheeks of the latter, whereas the ocular outline is not dissimilar. In the course of biometrical measurements, a new ratio—C/O, showing the relation between the maximum width of the face at the genal region (C) and the maximum width at the ocular region (O), was worked out along with the other ratios (Table IV.)

The general results of a biometrical examination of the mass of collections gathered in the course of locust surveys indicate that the whole material falls into a long series of forms showing a great variation of characters, with extreme *solitaria*

TABLE IV

Biometrical ratios in different phases

Ratio	*solitaria*	*transiens*	*gregaria*
E/F	1·88—2·05	2·06—2·15	2·16—2·34
P/C	1·617—1·430	1·462—1·315	1·387—1·243
M/C	0·888—0·757	0·887—0·722	0·805—0·705
H/C	1·258—1·666	1·224—1·071	1·187—1·040
C/O	1·02—1·08	1·03—1·07	1·17—1·20

and *gregaria* at either end, connected by an infinite gradation of intermediate forms. The Desert Locust, as a species, may be likened to a mass of plastic material, which yields to the moulding action of its environment in varying degrees and in different ways. In the extreme *gregaria*, sharp differences are noticeable from the *solitaria* forms, in various characters such as longer elytra, shorter femora, a bulge in the cheeks, a depression in the crest of the pronotum, a shortening of the prozona and a constriction in the prothorax. In the intermediate forms, changes may be manifested in only one or two of these characters, and the transition from the *solitaria* to the *gregaria* does not occur as a continuous gradation involving all the characters. Variations in the different characters do not appear to be linked together, but occur independently. A locust having a particular E/F ratio need not necessarily be in the same state of development from the point of view of the other ratios, although an extreme *gregaria* or extreme *solitaria*, may exhibit typical development of all the various characters. Since E/F has proved to be the most expressive and significant ratio, changes in the phase characters have been shown in most cases in terms of this ratio in working out the biometrical facies of locust population in preference to the others.

Biometrical facies of locust populations

General observations made in the course of locust surveys carried out during the years 1931-38 have shown that locusts are being continuously affected by changes in the environment. There may occur as the result of local breeding and multiplication not only an increase in numbers, but also a change in the phase of the population, according to the conditions of the breeding. A similar change in the composition of the population may take place in the event of an immigration from outside. In estimating the character of locust populations, careful biometrical examination of sample collections is necessary. If the results indicate a predominantly *solitaria* facies, the inference would be that there is no immediate danger of swarming ; on the other hand, if there should be a fair proportion of *gregaria*, it may be taken as an indication of tendencies for forming concentrations that may lead to incipient swarming if the conditions are favourable.

In comparing different populations, average biometric ratios may be used, but they do not convey any idea of the extent of variation in regard to phase development in the population. In some cases, the extent of variation is of greater significance than the mean ratio. For instance, the presence of a small percentage of individuals with high *gregaria* ratio among an otherwise mainly *solitaria* population is of particular importance, but it would be obscured by merely quoting the average ratio. The phase variation within a population could be best expressed by tabulating the actual number of individuals in gradations of E/F ratios of the value of 0·05 as done by Zolotarevsky [1938]. The frequency distribution of E/F ratios of similar value among the population can also be represented in graphs, as was done by Kennedy [1939]. In both cases the range and the size of variation is clearly indicated.

In the present study, a different method of showing the constitution of field populations has been adopted. On the basis of a biometrical examination, the population is grouped under 3 categories: *solitaria*, *transiens* and *gregaria*, according to the individual E/F ratios, and it is also further grouped according to the number of eye-stripes possessed by the individuals, which may be either 6 or 7 [Ramachandra Rao and Gupta, 1939].

In regard to the phase characters, it has been found from an examination of specimens collected from flying swarms that the great majority possess E/F ratios 2·16-2·34. On the other hand, the great majority of the non-gregarious locusts have E/F ratios below 2·05, usually between 1·88-2·03. Though it is not possible to fix any rigid limit between the phases in nature, an arbitrary division has been made for the purpose of classifying locust populations, under the following 3 categories : (1) *solitaria* 2·05 and below ; (2) *transiens* 2·06 to 2·15 ; and (3) *gregaria* 2·16 and above (Table IV). Murat [1939] in the course of a biometrical examination of *Schistocerca* in the Spanish Sahara, found that *gregaria* ratios ranged from 2·16 to 2·44 in females and from 2·17 to 2·28 in males, while his *solitaria* ratios ranged from 1·95 to 2·04. His results would appear to support our findings.

On the basis of the number of individuals found under (1) the phase groups of *solitaria* (S), *transiens* (T) and *gregaria* (G), and (2) under the eye-stripe groups, percentages are calculated, and the biometrical facies or index of the population is shown as percentage of individuals with different phase and eye-stripe characters in the following formula :—S : T : T G : : (6) : (7). **This method**

may be claimed to indicate at a glance the state of development of the population at any particular time or place from the view-point of phase, and has, moreover, been useful in identifying, populations in different areas and in tracing the movements of non-gregarious locuts. For example, the population found on the Mekran *reks* in January—March 1935 had the index :—76S : 23T : IG : 34(6) : 66(7), whereas in April—May 1935, the index was :—62S : 29T : 9G : : 67(6) : 33(7). On the other hand, the facies of the locust population on the Mekran *reks* after the locust incursion in July was as follows :—24S : 35T : 41G : : 88(6) : 12(7). The decrease of the proportions of *solitaria* ratios and 7-stripes and the increase of *gregaria* and 6-stripes between January and July was striking and suggested an immigration from outside. Similarly, the facies of the immigrant population in the Sind-Rajputana desert in July 1935 was :— 28S : 43T : 29G : : 92(6) : 8(7), which shows its affinities with the incursion population of Mekran. On the other hand, the index of the new brood found in October-November 1935 in the desert was 69S : 30T : IG : 29(6) : 71(7), indicating a reversal to *solitaria* during the monsoon breeding in the desert. The population found in the Lasbela area in December 1935 had the index :—59S : 41T : OG : : 64(6) : 36(7), suggesting an affinity between the desert brood and the autumn immigrants in the Lasbela area.

In working out the biometrical index, it is advisable to have as large a series of specimens as possible. In the course of the present studies, however, it has been found that even with as small a number as 20 or 25, fairly definite indications of the main characters of a population can be obtained.

Studies on the distribution of the solitary phase

Preliminary surveys

In 1930, at the time of the inauguration of the present scheme of Locust Research in India, there was no definite information available as to the source of the periodical infestations to which India has been subject. Although the generally accepted view was that the initial swarms reached India from a western direction, there was no positive evidence to indicate either that they had been derived from outbreak areas situated within Baluchistan, or that they merely formed a link in the chain of breeding areas connecting India with Arabia and Africa.

It was with the aim of detecting the presence of permanent or semi-permanent outbreak areas, if any, within Indian territory, that a special locust survey staff was appointed early in 1931, and stationed in Baluchistan (with Quetta as headquarters) in the first instance, as the province where such breeding grounds were most likely to be found. In the course of the year 1931, the survey staff examined the areas of Chagai, Lasbela, Mekran and Kharan between February and May. In September, a survey party traversed the desert areas of Kharan State. The Mekran and Lasbela coastal areas were revisited in September-October.

In the course of the following year, similar preliminary surveys were carried out in the rest of the desert or semi-desert areas of North-west India, viz. Kachhi, western Sind, Lasbela, eastern Sind, Jhalawan, Kech and Kolwa, Loralai, the Dera Ghazi Khan and Bahawalpore areas of the Punjab, the Thar area of Sind, and various areas of the Rajputana desert. Surveys of Sirohi, Palanpur Radhaupur and Cutch States carried out in the early months of 1933 completed the programme of surveys designed for obtaining a general knowledge of the distribution of the solitary phase locust within Indian limits. During the years 1932-1933, survey work was greatly facilitated by the provision of a one-and-a-half ton Ford motor-van, which was extensively used in carrying out most of the tours mentioned above. In all those places, however, where the motor-van could not be used, as in the interior of sandy deserts, journeys were performed on camels.

These extensive surveys amply served the purpose for which they were planned. The results obtained gave a general idea of the distribution of the *solitaria* locust population in the Indian area. It was, however, obvious that the records made in the course of these surveys had reference only to the conditions prevailing at the time, and that further surveys, repeated at different parts of the year, would be needed before any inferences in regard to their functioning as permanent reservations of the locust could be made. Moreover, in the course of survey work, a fluctuation of locust population was actually found to have occurred in certain instances.

Intensive regional surveys

In the light of the experience thus gathered, it became evident that the type of surveys that were needed at this stage should be such as were calculated to supply information on the exact effect of seasonal changes on the behaviour and activities of the non-gregarious type of locust. Consequently survey tours of the extensive type were given up, and, from June 1933, survey work was restricted to the areas where solitary locusts were observed to be present, such as parts of Mekran, the Lasbela area and various areas of the Indian Desert. Since 1937, owing to the detection of very intensive breeding in Kachhi and in the hill valleys of Baluchistan, these areas were also subjected to regular periodical surveys. The areas of the habitat of the locust were divided into circles

and sub-circles of convenient size, which were placed under the charge of Assistants and Fieldmen respectively for purposes of survey work. With the experience gained after a year of intensive surveys, a regular round of visits was plotted for each sub-circle and tours were arranged so that every area was visited once a month where possible (or at least once in two or three months, in particularly large or difficult areas), the staff being instructed to note down on the forms provided the number of locust adults or hoppers found, with particulars of the area covered, the condition of the environment and the state of activity of the insects.

By 1938 the survey comprised five circles, each subdivided in 2-5 sub-circles, of which there were 14 altogether.

Intensive local surveys

Though regional surveys of the type mentioned above have been of great value in giving a definite indication of the locust situation in the area concerned in different seasons, they could not give a continuous picture of the happenings at particular places. In the course of survey work, the data collected indicated not only that there was a fluctuation in the density of locust population at particular localities, but also that seasonal movements of the population were probably occurring. In order to obtain definite proof of such a phenomenon, intensive surveys were carried out in the neighbourhood of selected places throughout the year, commencing from 1934.

Such continuous records of locust activities have been obtained at the following stations :

1. Pasni : as a centre for the western *reks*, in the region of winter rainfall (records from 1932).
2. Ambagh : as a centre for the eastern areas of the Mekran coast, subject to summer rainfall (from 1933).
3. Chachro : as a centre for the south-western parts of the Indian Desert (from 1934).
4. Sardarshahr : as a centre for the north-eastern parts of the Desert (from 1934).
5. Nokh : as a centre for the central parts of the Desert (from 1935).

Method of estimating population density

In the earlier years of the present scheme, the number of locusts or hoppers observed or collected was noted down, as well as fairly detailed particulars of the areas examined. In certain cases, the surveyors gave rough estimates of the population density according to their lights, but they were not exactly comparable.

It was not till 1935 that a general formula for working out the population density of locusts under Indian conditions was evolved. This formula has since been in use, with slight modifications, and has, on the whole, proved quite satisfactory.

In the course of the surveys, it has been observed that the solitary phase adults generally rest on the ground in open patches between bushes and in most cases sit basking in the sun. This is generally the case, while the sand surface temperatures range roughly between 80°-100°F. (about 25°-37°C.). When the soil temperature rises above 100°F. (37°C.), the locust either changes its place by flight or crawls into shade, usually under a bush, for shelter from the sun's rays. On the other hand, when the soil surface temperature falls below 80°F. (about 25°C.), the locust is not very active, and sits basking in the sun as long as possible and ultimately retires for the night at the base of a bush. Therefore it is only within the range of 80°-100°F. surface soil temperature that the best results can be obtained in survey work. During summer months, the optimum time would be between 8 A.M. and 11 A.M. and between 4 P.M. and 7 P.M., while in the winter months the best period would be between 10 A.M. and 3 P.M.

When locusts are most active, they are very sensitive to the approach of men and rise up abruptly from the ground or bush and fly out. Curiously enough, they do not seem to mind camels or cattle unless these approach very near to them. When, however, an observer walks along waving a stick right and left very few locusts will remain undetected, within the range of 10 to 12 ft. on either side. A distance of 11 ft. has been fixed rather arbitrarily, as it is convenient for purposes of calculating fractions of a mile. The distance travelled by an observer during a survey can be determined either by his carrying a pedometer, or roughly by other means. Supposing, for example, a man had walked three miles and had found 10 locusts, the area covered by him might be computed in square miles by multiplying 3 miles by 22 ft., i.e. by 22/5280th of a mile ; thus, 10 locusts were found in an area 1/80th of a square mile, and the approximate density would be 800 per square mile. If a survey party of 5 men had been walking at a distance of about 20 to 30 ft. from each other, and had counted 20 locusts in 3 miles, the population density might be worked out by first computing the total area surveyed by all the 5 men, viz. $5 \times 22/5280 \times 3$ sq. miles, or 1/16 square mile, and then calculating the density which would thus be 16×20, or 320 locusts per square mile. The general formula would be as follows :—

$$P = \frac{L}{\frac{22}{M \times 5280 \times D}} = \frac{L \times 5280}{M \times 22 \times D},$$

P, being population density ; M, number of observers ; D, distance in miles ; L, number of locusts found.

If surveys are conducted during the optimum periods in respect of locust activity, this formula gives a fairly correct estimate of the population density.

During 1935, when a large incursion of locusts invaded the *reks* of Pasni, long stretches had to be covered in order to estimate the population and much of the survey work had to be done on camel back. As the locusts flew up, they were counted, just as in the case of foot-surveys. But instead of giving a range of 11 ft. on either side, double that figure was adopted in order to give due weight to the larger size of the camel, and the results obtained appeared to tally with those obtained by foot-surveys. During the subsequent years, however, when the locusts were comparatively few in numbers, camel surveys were found to be of little value and were discarded.

Owing to the extent of the area to be covered by the surveys, the scattered distribution of the locusts and the limited staff available for survey work, any precise determination of the density of population for large areas has been found to be beyond the bounds of practicability. Only random examinations have been possible and the surveys carried out can be considered to be only of the nature of 'samplings'. The number of locusts found in particular surveys is ultimately dependent on the peculiarities of their distribution at those times. The results of individual surveys are thus liable to vary a good deal, though carried out in the same region. In order to counteract the effects of individual variation and make the figures comparable, it was found desirable to work out the average of the density of population for the whole area surveyed. For working out the averages, the following method was adopted: The areas, in square miles, calculated for all the individual surveys, irrespective of whether locusts were noticed or not, were added together to get figures of the total extent of the area surveys. Similarly, the total number of locusts observed in the course of all the above surveys was obtained by adding up the individual results, and from these data, the average population density for the whole area was worked out.

The present method does not aim at any high accuracy, but is useful in providing a rough estimate of the density of locust population at different places and at different times, thus supplying a common basis for comparison in regard to the effect of environmental conditions.

Moreover, what is wanted is not an absolute census of locusts at any particular place, but only a rough indication of an increase or decrease of population, due to local multiplication or to immigration from outside. The experience of the last eight years shows that variations in densities up to 10,000 per sq. mile are not of much consequence, as they represent, in general, mere fluctuations of population. On the other hand, any increase of population above that limit, especially if it is spread over a large area, should be taken somewhat seriously, as there is a likelihood, if conditions should be favourable, of the formation of concentrations of locusts in restricted situations, bringing about crowded breeding. In localities where there is a high concentration of hoppers, such as may lead to an incipient outbreak, the density of the hopper population may reach a million per square mile. A further degree of concentration—probably of the order of 20 to 100 millions per square mile, is presumably needed for the actual formation of a swarm.

Analysis of the survey data 1931—1939

The results of the surveys regularly carried out as described above, have been compared with the weather conditions in the respective areas during each year. The sequence of events in the life of the solitary phase locusts throughout a year shows, on the whole, a striking correlation with the seasonal weather changes, and deviations of weather conditions in particular years are reflected in corresponding fluctuations of the locust population in different areas. The normal annual cycle and its variations, observed each year, are briefly described below.

The overwintering of adults

Only scanty information is available with regard to the winters of 1930-31 and 1931-32. In parts of the Rajputana desert and in the Lasbela and Mekran areas considerable overwintering occurred during the winters of 1933-34, 1935-36, 1936-37, and 1937-38; in these years the breeding in the Sind-Rajputana desert during the preceding summer had been fairly heavy and continued late in the season. On the other hand, during the winters of 1932-33, 1934-35, and 1939-40, there were no overwintering adults in the Rajputana desert and very few in the Lasbela and Mekran. In 1932 there was no rainfall in Rajputana after the 15th August, and in 1934 there was none in September, while in 1938 and 1939, the monsoon rains were very poor in most parts of Sind and Rajputana, so that breeding in these four years was restricted and there was practically no late breeding. Thus, the occurrence of large numbers of overwintering adults is dependent on the late breeding in the Rajputana desert areas during the preceding summer. Locusts of the earlier brood appear to leave the desert areas by September and gradually drift westwards to Baluchistan, subsequently passing into Iran. If there is any late breeding, further flights from the desert follow during October and November, and these late

adults overwinter partly in the desert, and partly in Lasbela and Mekran.

Frosts in many parts of Upper Baluchistan, especially at the altitudes above 4,000 ft., occur almost every night during the greater part of December, January and February, and there are records to indicate that swarms suffer a high percentage of mortality in these upland areas during winter, and cases of mortality among the solitary phase locusts during severe spells of cold weather have also been noticed. In winter, locusts seek the base of thick bushes like those of Siniya (*Crotalaria burhia*) during nights but they generally crawl out during daytime to bask in the sun. In the Mekran coastal areas and in the desert, winters are not severe, but sometimes, especially in the northern parts of the desert as in the Bikaner area, frosts occur on several nights during cold waves, and at such times locusts have been found dead at the foot of the bushes. The following observations made of the behaviour of locusts in a cage with wire-gauze sides kept in the open during the winter months at Quetta, however, indicate that locusts can withstand fairly low temperatures. In a cage in which several hopper had been introduced among small bushes in September, a few became adults in October, but owing to the setting in of cold weather rather early by the middle of October and the occurrence of frosts on several nights, the rest of the hoppers did not show any further growth during the winter. They were found hiding either at the base of thick bushes or in crevices between the framework of the cage and the ground during nights, and came out of their hiding places in the morning on sunny days. During the whole day they remained basking in the sun, and fed a little at midday. They did not emerge on cloudy days. The locusts—both hoppers and adults—survived till the beginning of January, so hat they withstood air temperatures of 17°F. (about —8°C.), but with the fall of snow in the second week of January and the subsequent thaw, they were observed to succumb to the wet cold; the minimum temperature recorded in January was 13°F.

In the course of survey work, observations were made on he overwintering habits of a few grasshoppers. At Quetta, *Acrotylus humbertianus*, Sauss., was found overwintering under grass in a lawn at a depth of about 1½ to 2 in. and to have survived a snowfall of 4 in. in March 1931. *Anacridium aegyptium*, L. was found hiding in a niche in a building at Quetta in February 1931. At Ahmedwall in Chagai (3,000 ft. altitude) several specimens of *Thisoicetrus persa*, Uv., were collected in March 1931, hiding in crevices in stony ground, having survived a fall of snow. At Chachro in the cultivated area of the desert, some thorn fences were dismantled in February 1935 and several grasshoppers—*Cyrtacanthacris tatarica*, L., *Anacridium aegyptium*, L., *Euprepocnemis alacris*, Serv., etc.—were found. The overwintering is probably a fairly common phenomenon among Acrididae in India.

Except during the winter of 1937-38, when hoppers were also found passing the winter in the Thar area in small numbers along with the adults, the Desert Locust would appear to overwinter only in the adult stage.

Spring breeding on the western reks

The extent and intensity of spring breeding on the western *reks* of the Mekran coast would appear to be directly commensurate with the amount of winter rainfall received. Fairly heavy spring breeding was noticed in 1933, 1935 and 1939 as a result of heavy winter-spring rainfall, while during the spring of 1932, 1934 and 1937, there was an absolute absence of breeding in consequence of an almost total failure of winter-spring rainfall. In 1931, 1936 and 1938, winter precipitation occurred all over the coast, but was below the average, and the spring breeding was, accordingly, light to moderate in character.

Late spring breeding in the interior of Mekran

a. Spring migration. Since 1933, regular surveys of the interior of Mekran were carried out throughout the year, and as a rule, very few locusts were noticeable in the interior of Mekran during the winter months. From March onwards, however, increasingly large numbers were usually met with. From the biometrical characters of the population met with in the interior during the period March to May in the years 1935 and 1936, and from the evidence furnished by the presence of green algae [Ramachandra Rao, 1940] on the wings in 1937 and 1938 in similar population, it is fairly obvious that they were derived from the coastal population of Mekran. The occurrence of yellow-winged forms carrying green algae on the wings in Kachhi-Bolan area in 1937 and 1938, and the finding of a yellow-winged male with mature green algae on the wings as far north as Dalbandin on 4th April 1938, are clear indications of the existence of a general migration from the coastal areas of Mekran and Lasbela into the valleys of the interior with the advance of spring. Similar migration of swarms has been noticed in Baluchistan in the spring months during the last swarming cycle. The probable cause of such migration may be that a rise of temperature accompanied by desiccation starts earlier on the coastal plains than in the upland valleys to the north, which by reason both of a higher latitude and a greater altitude offer more suitable ecological conditions for the breeding of the locust till late in the season.

b. Development of outbreak centres. As a result of the occurrence of good showers of rain in spring in the interior of Baluchsitan in 1935, concentrated breeding was noticed in suitable localities between April and June, leading to the development of incipient swarms in the Kech Valley, in the Panjgur area and in south Kharan. In these cases the breeding represented the second spring generation derived from parents produced on the coast.

In 1936, an outbreak centre was found to have developed in the Kilwa area in March-April, but it was formed by the concentration of overwintered individuals of the old generation. Fairly good breeding also occurred in Kulanch at about the same time. In addition, light breeding representing the second generation of spring was noted in June at Nigor-Kan-Daf in the Panjgur area.

In 1937, owing to the failure of rains on the coast, most of the locusts would appear to have migrated into the valleys of Mekran and Upper Baluchistan. An outbreak centre developed at Sheh Lakhra in the Porali valley of Lasbela in the spring months. Heavy breeding occurred on the Kachhi Plain, and in the Bolan valley in April, May and June, and there is little doubt that the infestation had been started by locusts derived from the Lasbela and Sind-Rajputana areas, where overwintering had been noticéd. There was, moreover, a fair amount of breeding in the valleys of the Panjgur area, especially in the Gar-Parom section in June and July, representing the second generation of the season.

In 1938 there was little breeding in the interior in view of the defective rainfall, except in the Kulanch area.

In 1939 heavy winter rainfall occurred both on the coast and in the interior of Mekran, and good breeding was noticed in the Kulanch, Kech and Kolwa areas between March and June, and there is reason to believe that the breeding in these areas might have taken the complexion of outbreak centres if the initial locust population on the coastal areas of Mekran in the winter of 1938-39 had been greater. Heavy breeding would appear to have occurred in the Kachhi-Bolan areas also in the spring of 1939.

In 1926, the year of the commencement of the last great cycle, very heavy rainfall occurred in January, both on the coast and interior of Mekran, and led to heavy breeding on the coast. Subsequently, there was good rainfall in the interior in March and later on in May, which presumably induced widespread formation of outbreak centres in Kulanch in May, and there is reason to believe that incipient swarms developed at the same time also in the Kech and Kolwa valleys.

Movements in summer

The climate of the western parts of Baluchistan resembles that of the regions further west, such as Iran, Iraq and Arabia. It is of the Mediterranean type with rainfall mostly in winter and spring, and with pronounced summer drought. Rains practically cease in March or April, and by the end of April or the beginning of May there is a distinct rise of temperature accompanied by a fall of humidity. In years when there is a failure of winter rain, conditions of desiccation may set in as early as the middle of April, whereas in years of more than average rainfall, this occurs by the middle or end of May. These climatic changes generally take place more or less gradually with the advance of the season, but abrupt rises also occur fairly frequently, either as the result of a heat wave or in the wake of one of the western distrubances. High temperatures are generally accompanied by dry hot winds (*gorich*) from the north or north-west, and may persist for a week or ten days, after which milder weather may prevail till another heat wave sets in. In the Mekran area south-west winds from the coast generally prevail in the afternoons during these intervals.

With a general rise of atmospheric maximum temperatures to over 100°F. (the soil surface temperatures being naturally much higher), and a corresponding fall of humidity, locusts would seem to feel an urge to leave the area, and while the south-west winds prevail, move up through the valleys of southern Baluchistan into Kachhi and west Sind, and thence into south-west Punjab and Rajputana. On the other hand, when the north-west winds are active, locusts find their way into the coastal areas from the interior. Ultimately, however, even those reaching the coast gravitate into the desert areas via Lasbela and Sind. The following examples illustrate the variations in summer movements in various years.

In 1932 a definite incursion of locusts—mostly of the *gregaria* type—occurred on the 24th May on the Mekran *reks*, and was associated with the prevalence of dust storms from the north that had developed during the heat wave of 22nd and 23rd May in Upper Baluchistan. In July 1935, a similar incursion of locusts, but of much greater magnitude, likewise connected with the development of conditions of high saturation deficiency in the interior, was experienced in the coastal areas of Mekran and Lasbela, and in the Thar area of Sind, during the second week of the month. Similar but much lighter incursions were noted in the Pasni area in May 1936, in June 1937 and June 1938, and in all cases a sudden rise of temperature in the interior was found to be involved.

In the Sind-Rajputana desert region, regular observations were begun only from June 1933,

and during the period 1933 to 1939 few locusts were noticed during the winters, none being observable by April. Specimens of a recently developed generation were always found appearing in May or June in most parts of the Sind-Rajputana desert, and as these could not have developed locally it is fairly evident that they represented migrants from the western areas of winter-spring breeding.

With the development of high temperatures in the western areas, locusts would appear to quit them in May-June and to migrate with the south-westerly winds generally prevalent at this period (except during a hot wave) towards the north-east or east into Sind, S. W. Punjab and Rajputana. As a rule, most of the early migrants reach the northern parts of the desert, the migration being directed to the southern parts only when north-westerly winds prevail as a result of an abnormal rise of temperatures in Baluchistan.

In the case of the Thar-Malliani area, locusts may arrive there directly from the western areas, but may more often be conveyed there from the north or north-east by winds connected with the passage of a monsoon depression. In 1938 no locusts were observed around Chachro till the 22nd July, when with the fall of heavy rain due to a depression, fairly good numbers were noticed on subsequent days.

In 1937, when heavy spring breeding occurred in the Kachhi and Bolan areas, locust individuals of a new generation began to appear in the Jaisalmer-Bikaner areas as early as the middle of May. As owing to lack of rainfall there was no spring breeding in the Mekran coastal areas nor any extensive multiplication in the Mekran hinterland, there is reason to believe that most of the migrants found in May and June had originated from the Kachhi-Bolan areas or from the Shah Lakhra area in Lasbela. In 1938 there was no breeding in the Kachhi area and but little in Bolan; and few locusts were met with till the end of June in the Jaisalmer-Bikaner areas. In 1939, on the other hand, fairly good breeding occurred in the Kachhi area, and the earliest immigrations of the year—which were found in June in the Jaisalmer-Bikaner area—were presumably derived from the Kachhi area.

As the infestation found in Kachhi-Bolan area in the spring of 1937 had been derived mostly from the overwintered locusts found in the Jaisalmer-Bikaner areas, there is probably a linkage between the two areas in regard to locust breeding.

Summer breeding

(*a*) *Sind-Rajputana Area*. The migrants begin to appear in the Sind-Rajputana area generally by the end of May or the beginning of June and the immigration may continue up to the middle of August. By the middle of June a fair proportion of the immigrant locusts is sexually mature, and if the monsoon rains commence by the latter half of June, as they did in 1933, 1934 and 1936, oviposition takes place almost immediately. In 1938, an inch of rainfall was recorded at Bermer on the 31st May, and hoppers were noticed there already by the end of June.

July is generally a month of good rainfall, in which egg-laying is in progress throughout the month, and the first hoppers may be expected by the middle of the month. The June-July batch forms the first monsoon brood, the new adults of which usually appear by the middle of August. Should there be good rainfall also in August, the immigrant locusts may be able to lay a second, and sometimes even a third, batch of eggs in some part or other of the desert, so that hoppers of the first generation may be found up to the middle of September and may continue to transform into adults even up to the end of September.

Generally, however, a break of 2 to 5 weeks' duration in the monsoon rainfall occurs either in July, or in July-August, or in August-September. This has the effect of causing the sand-soil moisture to dry up, and sometimes of raising the saturation deficiency of the atmosphere, as a result of which locusts find the conditions unsuitable for further egg-laying and usually leave the area.

When there is sufficient rainfall in August, adults of the new generation appearing at the beginning of August are able to attain sexual maturity by the end of August or the beginning of September, and to lay eggs that result in the second monsoon generation. As the last batches of eggs of the old generation may also be laid at the same time, an overlapping of generations is bound to occur at this period, though by the end of the breeding season the hopper population may be expected to be made up purely of the second generation.

The production of the late brood—which in effect is mostly composed of the second generation of the monsoon period—is a factor of considerable importance in locust epidemiology. The greatest increase in numbers would occur only if one fairly large brood is quickly followed by a second one within the same breeding period. Otherwise, a considerable decrease in numbers is likely to occur if the bulk of the new generation has to undergo the usual seasonal migration and hibernation before it can breed in the spring, in view of the likelihood of numerous casualties due to adverse weather conditions and natural enemies. In 1926, there was fairly heavy and almost continuous rainfall during July, August and September in the desert areas, especially in the southern parts of the desert where heavy rain occurred in September. Consequently fairly extensive breeding in July-

August was followed in September-October by a second generation mostly in the southern desert, where, favoured by the dynamics of depressions (see below), concentrated breeding was brought about, resulting in the formation of large swarms. The latter spread southwards into Cutch and Kathiawar, north-westwards into southern Punjab and westwards into Sind and Baluchistan, and thus initiated the last locust cycle of 1926-1931.

In 1935, on the other hand, good precipitation in July was followed by deficient rainfall and partial drought in August and September, so that the fairly good breeding that commenced in the wake of the incursion of considerable numbers of locusts from the west was interrupted in August, and there was only a feeble development of the second monsoon generation in September-October.

In 1933, when heavy multiplication occurred as a result of heavy rainfall, especially in the northern areas, a few loose swarms had apparently been produced, which were reported from the outskirts of the desert areas near Muttra and in the Bikaner-Bahawalpur areas.

In 1936, a considerable increase of *solitaria* population was noticed in the Jaisalmer-Bikaner areas in November as a result of late breeding induced by heavy rainfall in August, but no concentrated breeding apparently occurred.

From the experience gained during the last few years, it is obvious that August and September are rather critical months in respect of locust breeding in the desert areas, as the extent of multiplication during the particular season is entirely dependent on the character of the precipitation received during this period.

(*b*) *The Baluchistan Areas.* Summer breeding generally occurs in the Lasbela, Kachhi and Mekran areas in which the monsoon extends its influence. Between 1931 and 1939, there was no summer rainfall in the Lasbela and Mekran areas in 1931, 1935 and 1939 and consequently no summer breeding. On the other hand, in 1932, when a depression carried heavy rainfall into the Lasbela area and into the coast and interior of Mekran during July, extensive breeding was observed all over these areas in July-August-September. In 1933, also, heavy rainfall occurred in July in the Lasbela area, but in Mekran the rains were comparatively light in the interior (Kolwa, Kech and Panjgur) and very light along the coast. Heavy breeding was observed in the Lasbela area between August and October, but in Mekran there was only light breeding in the interior, and none on the coast. In other years, varying amount of rainfall was associated in Lasbela with proportionately varying amount of breeding. In Mekran, however, breeding was noticed in some quantity only in 1937 and 1938 in Kolwa and Panjgur in summer.

Flights induced by dust storms or thunder storms

In the course of intensive observations made in the Sind-Rajputana area between 1934 and 1938, it was often noticed that, soon after rainfall, locusts were found present in localities where they had not been seen previously. It was at first supposed that the presence of locusts was due to the active attraction exercised by heavy precipitation, but observations made in the course of survey work made it clear that in most cases they are brought into the area by the storms that usher in the rain. On 23 August, 1937, large groups of solitary locusts—which were sufficiently numerous to be mistaken for a loose swarm—were reported to have been seen flying with the wind over the town of Sardarshahr at dusk just prior to the occurrence of a thunder storm. It is surmised that these locust groups had been derived from the Reni area to the north-east, where large numbers of adults of the new brood were known to have been present, and that the latter had, in view of the unusual drought that had been prevailing at the time, been excited into activity by the cool, moist winds of the oncoming thunder storm and had allowed themselves to be carried by the storm into new areas. A similar case was observed in the Kolwa area in Mekran in July 1937, when a fieldman found fairly large numbers of locusts after rain storms, though none had been found prior to rainfall. In a third case, few locusts were seen in the Nokh area during first week of August 1936, but subsequent to the abnormally heavy precipitation during the second week (12th to 16th), large numbers of them were met with in the same area. Apparently they had been carried into the area by the cyclonic movements of the storms accompanying the passage of the depression. Further instances of this kind were noted in July 1938, when the earliest appearance of locusts during the summer synchronized with the first monsoon shower at Chachro as well as at Nokh [Bhatia, 1939].

In this connection, certain observations (as yet unpublished) which had been made by Khan Bahadur M. Afzal Husain, Dr Taskhir Ahmad and others at Lyallpur in August 1931, on the behaviour of caged locusts, are of particular interest. A large number of locusts, captured from swarms, had been confined in a large wire-gauze cage in the open, and it was found on two occasions that the locusts began to fly about in a state of great excitation and dash against the wire-gauze sides some time before the approach of a dust storm. If in nature locusts similarly respond to changes in the atmospheric temperature, humidity and pressure associated with the approach of rain storms, they would rise into the air of their own accord to meet the winds, and thus get conveyed by them to likely areas of rainfall.

Therefore, the occurrence of thunder storms, or the passage of depressions in summer, is of special significance in the development of outbreak centres in the desert areas.

Autumn migration

With the withdrawal of the monsoon current from North-West India during September, the desert becomes an area of drought accompanied by high temperatures. In years of more than average precipitation during August-September, as in 1931 and 1933, the change to conditions of drought is delayed, occurring only by the middle of October. On the other hand, in years in which rainfall in August-September is defective, as in 1932, 1934 and 1935, conditions of drought develop fairly early in September, and in 1937 an unusual drought developed during a long break in the monsoon in August. During the monsoon months, the maximum temperatures in the desert rarely reach 98°F., whereas they may rise as high as 107°F. during periods of drought developing after the monsoon current ceases. The adult locusts of the solitary phase rest and bask on the surface of sandy soil, and as the temperatures on the surface of sand heated by the direct rays of the sun will naturally be high and the percentage of atmospheric moisture in such locations will also be lower than that in the screen, the discomfort caused to the insect would be very great, so that it generally tries to flee from such situations.

Locusts generally leave the Sind-Rajputana desert area in September-October, and as north-easterly or easterly winds are usually prevalent at this period, the bulk of them would appear to fly towards Sind and Baluchistan. In one carefully observed instance in September 1936 at Chachro, a dust storm that appeared from the north-eastern direction in the afternoon carried off most of the locusts in that area. As by the end of the month the population at Ambagh was found to show a sudden rise, it is surmised that a migration in a westerly direction had taken place. Similarly, in September 1937, the greater part of a fairly high locust population found in the neighbourhood of Chachro was noticed to have been swept away by a depression that passed westwards over that area on the 10th September. More usually, however, emigration from an area is gradual and may be spread over a large number of days, while the conditions of drought last. Much of the autumn migration takes place generally during October, but it may extend up to the middle of November.

In general, however, the heat abates by November, and a slight rise of humidity also occurs, so that locusts do not find the same urge to leave the area. When there is late breeding, most of the adults that are produced by the close of October or during November do not show any indications of leaving the area, and the great majority of them apparently pass the winter in the desert areas, though a certain proportion may, and do, migrate in the course of the winter season during the short spells of comparatively hot weather that sometimes develops there.

In the autumn of 1937, periodical observations were made at several points in the semi-desert area stretching between the banks of the Indus and the Hab rivers, in an attempt to get information in regard to the progress of migration. It was found that locusts were noticeable mostly on the sandy beds of various dry water-courses that drain the semi-desert country. It was also observed that, while locusts were met with during October and November, they were not seen in December, indicating the cessation of migration in winter.

From the information available, it looks as if migration takes place in the form of hops, covering about 10 to 20 miles at a time, the migrating locusts alighting wherever they find sand patches covered with light vegetation for purposes of resting and feeding. Presumably it may take about a week or ten days for migrating locusts to cover the distance between the Indus and Hab rivers, though with a strong north-east wind backing them, it may take much less.

Observations made in 1935-38 indicate that autumnal migration probably occurs in a series of waves that are generally concurrent with periods during which the dry north-east winds are prevalent in Sind, Baluchistan and Rajputana. In many cases, each wave of migration could be traced to a certain extent from the Rajputana area to the Lasbela area, and thence to the Ormara and Pasni *reks*.

Very little is known as to the routes by which migrant locusts reach the Mekran *reks* from Rajputana and vice versa, but there is no doubt that migration is probably guided partly by the direction of the prevalent winds and partly by the orientation of the valleys in the mountainous areas of Baluchistan through which they have to pass. It is probable, for instance, that the migrants that reach the Rumra and Pasni areas from Sind pass through the Kolwa valley. In regard to the locust populations found on the various coastal *reks* of Mekran, it was often noticed that a progressive rise of density occurred in the autumn from east to west, and it is possible that a gradual migration along the coast occurs during the autumn, winter and spring months from east to west, and probably extends into the Iranian areas.

The concentrations of locusts that are almost always noticeable on the coastal *reks* of Mekran are probably to be explained as incidents of

seasonal migration. In summer, locusts get into the *reks* from the interior from a northern or north-western direction, and in autumn and winter from a north-eastern direction. On reaching the coast their migratory flights are presumably halted by a sight of the great barrier of the sea, and the attraction exercised by the *reks* with their scrub vegetation would account for their presence in such numbers along the sea-coast. It is possible that a fair number of locust individuals may be carried by strong winds across the Gulf of Oman into Arabia as, e.g., in the winter of 1936-37 there was some indication that a migration of individuals had taken place across the Gulf into the Muscat-Sharjah area.

Spring breeding in the Sind-Rajputana desert areas

Usually the spring rainfall in the desert is not high enough to induce breeding, but in the spring of 1936 light breeding occurred in north Jaisalmer area. In the spring of 1937, fairly heavy rainfall occurred in the Jaisalmer-Bikaner areas, and as a result fairly widespread but light breeding was noted in April in many places in the northern parts of the desert. Adult locusts of the new generation were found in May. In 1935, good rainfall occurred in spring but breeding did not follow on account of the absence of locusts in these areas.

During the period 1934 to 1939, no spring breeding has been noticed in the southern parts of the desert.

Parallelism of the annual cycle of activities of the *Solitaria* and *Gregaria* phases

In view of the knowledge gained during the last nine years of the life activities of the *solitaria* phase in the Indian area of its habitat, it might be useful to compare it with what is known of its *gregaria* phase during the last locust outbreak of 1926-31. A short summary of the general scheme of swarm movements is given below.

The winter period

Swarms are generally inactive during the winter months, especially during December and January. During the winters of 1928-29 and 1930-31 there was no over-wintering in the Indian area, but in 1926-27, 1927-28, 1929-30 and 1931-32 large numbers of locust swarms were found in the winter season chiefly in the coastal areas of Mekran and Lasbela, parts of the Sind valley, the Kachhi plain, parts of S.W. Punjab, the outskirts of the Indian desert, and the foothills of the Punjab ranges.

Spring breeding and migration

Mekran. With the fall of winter rains, the swarms over-wintering in the coastal areas may become mature and lay eggs in suitable places. At the same time there occurs a migration from the coast into the interior, generally in a north or north-east direction into the Kech and Kolwa valleys and thence into Jhalawan. Other swarms may move into Panjgur, Kharan and Chagai from the southern parts of Iran. From Chagai swarms may move into Sarawan and Quetta-Pishin, or into the Kandahar valley in Afghanistan via Shorawak and Chaman, and thence through the Arghastan valley into the Kurram valley in the N. W. Frontier Province, reaching the latter by May-June.

Kachhi. Swarms wintering in the plains of Kachhi and west Sind enter the mountain valleys of Upper Baluchistan through the gorges of the Mula, the Bolan and the Nara, ultimately finding their way into Sarawan, Sibi, Quetta-Pishin, Loralai and Zhob districts.

Punjab. Swarms become active in spring and may concentrate and breed between February and April, in districts receiving winter rainfall. There was considerable spring breeding in 1927, 1928, 1930, and little or none in 1929 and 1931. There may be some breeding in spring also in the sub-montane areas of the United Provinces, such as Kumaon.

Sind and Rajputana. Breeding rarely occurs in spring.

Baluchistan. Breeding takes place only in places where good rainfall has occurred. It first occurs in the low-lying coastal areas and in the Kech and Kolwa valleys (February to March), after which breeding is observed in the higher valleys, such as Panjgur, Kharan and Chagai (March to May) and lastly in the uplands of Sarawan, Quetta-Pishin and Zhob (May-June).

The adult locusts belonging to the earliest brood produced in the southern valleys may reach the uplands in the interior in April-May and may lay eggs if conditions are suitable.

Summer migration

Pink swarms of the adults of the new generation produced in spring in Mekran and Chagai fly in May in a north-easterly or easterly direction across Jhalawan and Sarawan till they reach west Sind, Kachhi and south-west Punjab in June. The swarms produced in the uplands in June also fly eastwards into the Sind-Punjab area.

The new generation developed in the Punjab in April-May is generally swept eastwards into the United Provinces, Central India and Bihar by the hot winds from the north-west that blow in May-June on the Indo-Gangetic plains.

The main cause of the eastward migration of swarms from Baluchistan would appear to be the development of conditions of high desiccation that set in, in the interior, at the end of spring and the prevalence of strong south-westerly winds, which carry them into Sind and the Punjab.

The pink swarms from the Baluchistan area generally reach the Sind and South-West Punjab areas in June, and gradually fly eastwards into Rajputana, the east Punjab, and the United Provinces during June-July.

Summer breeding

Baluchistan. The greater part of Baluchistan falls within the zone of summer drought and usually very little summer rain is received, but depressions of the monsoon period may carry considerable rainfall at times into the eastern parts of the country, such as Loralai, Sibi, Zhob, Kachhi, Jhalawan and Kolwa, in which case breeding may occur in these areas. In Lasbela, however, summer breeding is the rule, as it is subject to the influence of the monsoon.

Sind-Rajputana. With the fall of rain, the migrant swarms attain maturity, and there is considerable breeding in the sandy desert areas of Sind and Rajputana. In years of extraordinary rainfall, as in 1929, a great deal of multiplication may occur also in the alluvial areas of Sind.

Punjab and United Provinces. With the development of depressions from the Bay of Bengal, the dominant wind-direction in July-August is usually east to west, and consequently most of the swarms that had reached Bihar and Central India in June are swept back to the west and begin to breed in the Punjab and the western parts of the United Provinces.

The adults of the first generation of the monsoon begin to appear in August, and they are ready to fly in September. There is usually a single generation in summer, but if heavy late rainfall is received in August-September the old generation may continue to lay further batches of eggs and, in addition, the new generation may also begin to breed in the desert areas and in parts of the Punjab. These will assume adult condition only by October-November.

Autumn flights

With the withdrawal of the monsoon, north-west India becomes an area of high temperatures and low humidity, and the change in the climatic conditions has the effect of driving the swarms out of the Punjab, Rajputana and United Provinces. On the Indo-Gangetic plains, westerly winds develop in September-October and may convey the swarms eastwards into Bihar, Bengal and Assam. Some of them may also move into East Rajputana and Central India, and thence southwards into Central Provinces and Bombay Presidency. In western Rajputana, some swarms may be carried southwards into the Kathiawar-Gujarat areas, but a great many are also swept westwards into Sind and Baluchistan, regions where after a period of over-wintering they can breed again in the spring following. Of the flights that move east or south few would seem to survive, as they do not meet with conditions favouring further multiplication.

Comparing the cycle of life ativities of phase *gregaria*, as outlined above, with that of phase *solitaria*, one notices a remarkable parallelism in the main scheme of annual events. In fact, there is the same sequence of concurrences : (1) Over-wintering followed by breeding in the winter rain areas, (2) spring migration from the coast into the interior, followed by breeding in the upland valleys, (3) summer migration to regions eastward as a result of the development of conditions of drought in the west, (4) summer breeding in monsoon areas, and (5) autumn migration—in part at least westwards into Baluchistan owing to the autumnal rise of temperatures with the withdrawal of the monsoon current.

The main differences between the two phases would seem to lie in the greater degree of activity of phase *gregaria*. Both *solitaria* and *gregaria* are similarly affected by the same meteorological and ecological factors provoking them to make long distance migrations, but phase *gregaria* owing to its occurrence in swarms is capable, under the influence of mob psychology, of reaching longer distances and covering wider areas. The area of migration of *solitaria* individuals is confined usually to the coast and interior of British and Iranian Mekran on the west, to the Rajputana desert areas on the east, but extends sometimes as far north as Chagai on the Mekran side and up to Spez and along the Bolan valley, and in the Rajputana area may extend into Patiala territory. On the other hand, swarms of *gregaria* may reach as far north as the Himalayas, as far east as Assam and as far south as the Madras Presidency.

A CHANGE IN THE CONCEPTION ON THE ORIGIN OF OUTBREAKS

At the period when the present investigations were commenced, the general view as to how locust infestation cycles recurred was somewhat as follows. With the breakdown of a locust cycle, the swarms would diminish in number and size and ultimately disappear, and simultaneously the area of their distribution would also gradually become narrowed down to the limits of their permanent breeding grounds, where they would be found as scattered individuals of the solitary phase. If favourable weather conditions, such as heavy rainfall, should occur, intensive breeding would be induced and lead to the building up of a large population during one or two successive seasons. Sooner or later, swarms of the gregarious phase would be formed and invasions of large areas of surrounding country would follow.

The observations recorded during our surveys indicated, however, firstly that the population found in the breeding grounds was rarely of a static character and was marked by strong fluctuations in density, which was affected not only by local breeding, but also by an immigration or emigration of individuals. Secondly, *solitaria* individuals have been found to be capable of migrating long distances, so that those bred in winter-rain areas can reach regions of summer rainfall and vice versa, at the change of the seasons and breed there. Thirdly, phase transformation has been found to occur, not in what have been called the permanent breeding grounds, but in certain ecologically peculiar locations—the outbreak centres—often situated far from them.

From the field observations in regard to the habits and behaviour of the solitary phase in the Indian area, the following would appear to be the general sequence of events in regard to the starting of a new cycle of locust infestation in north-west India.

1. Granting that winter rainfall is heavy and early in the western areas of Baluchistan and that a fairly high population of solitary phase locusts is present on the *rek* areas of Mekran, passing the winter in the comparatively warm climate of the coastal plains, a fairly widespread and intensive breeding might be expected to occur on the sandy *rek* areas; the new generation of locusts would begin to appear by the end of March or the beginning of April.

2. By February, with the general rise of temperatures a migration of locusts from the coast into the valleys of the hinterland would begin. By March, most of the old over-wintered locusts would have reached the interior, and in April and May the new generation from coastal *reks* would follow. The interior of Mekran is a hilly area, most of which is either rocky or stony, and soft soils—mostly fine silts or sandy loams, are to be met with only on the bottom of the valleys, on which most of the patches of cultivation are to be found, generally along the banks of streams or water-courses. In some places, small mounds of fine, wind-blown silt are also to be seen, sometimes on the banks of streams and sometimes at the base of hills. Locusts migrating into the interior are, therefore, attracted to the cultivated fields, and as the soft wet soils in such places offer suitable locations for egg-laying, crowded oviposition would occur. The hoppers hatching therefrom would appear to congregate in the cultivation and undergo a transformation of phase there.

3. Such outbreak centres might occur not only in Mekran, but also in Lasbela, Kachhi and the hill-valleys of Upper Baluchistan, such as Bolan.

4. With the development of dry weather in summer, most of the locusts produced in Baluchistan and southern Iran would appear to migrate eastwards into Sind, Rajputana and Punjab, where they begin to appear in May-June. The migration generally continues into July and August, and quite a large body of migrants may become congregated in various parts of the desert area. Breeding would begin in July, in the event of good monsoon rainfall, and the new generation of locusts produced in the desert might be produced by the end of August. Should further heavy rainfall occur in August and September, a second generation would be produced in the desert, and very often the depressions that pass over the desert from east to west would have the result of causing fairly dense concentrations to occur in the south-western or western parts of the desert, and thus bring about the formation of large swarms.

5. With the development of dry weather, in September-October, the swarms produced in the Rajputana desert area would become dispersed, most of them leaving the area westwards into the Sind-Baluchistan areas, where they can overwinter and breed in the following spring.

From the above, it is obvious that the real danger points are (1) the formation of outbreak centres in the interior of Baluchistan in late spring and (2) the intensive multiplication in the southern and western parts of the desert in September-October. It is both these areas that will have to be watched for and checked in time if the development of a new cycle of locust infestation is to be prevented.

It should be added that the complex of outbreak centres composed of the winter-rain and the summer-rain areas, connected by migrations of locust population, is probably continued into southern Iran and eastern Arabia.

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ABSTRACT

A RÉSUMÉ OF THE SOIL WORK CARRIED OUT UNDER THE CENTRAL PROVINCES RICE RESEARCH SCHEME

(Report on the soil work carried out under the Central Provinces Rice Research Scheme, Raipur, Government Printing, C. P. and Berar, Nagpur, 1942, Price Rs. 1-8)

THE total cultivated area in the Central Provinces and Berar amounts to 2,49,13,000 acres and the percentage of the area under important crops is, rice 21, cotton 20, *jowar* 17 and wheat 16. It will thus be seen that from the point of view of area, rice is the most important crop of the province and particularly that of the Chhattisgarh Division. Rice is grown on a variety of soils possessing widely varying characteristics in respect of their mechanical and chemical composition. Certain varieties of paddy have been reported to give different yields on varying classes of soils, and their requirement in respect of water for normal growth on different classes of soils is not a constant factor. These and other cognate problems could not be intensively studied by the Department in the past due to inadequate staff and resources. It was therefore proposed to investigate these problems with the help of the Imperial Council of Agricultural Research and the Rice Research Scheme at Raipur was approved by that body for this purpose. The work under this scheme started in September 1932 and was carried out on 2 lines, (1) botanical work consisting of selection of better varieties of paddy and evolution of purple hybrids to enable eradication of karga weed (which is very similar in appearance to the paddy plant) which is found to grow extensively in rice fields, (2) biochemical work involving a growth of paddy, standardization of analytical methods and other cognate problems. Some of the investigations under this head although academic in nature were considered to be necessary in order to obtain the required information in respect of rice soils of the Province.

The report under reference gives an account of biochemical investigations carried out according to the approved technical programme of work and the results obtained are briefly summarized below.

A PRELIMINARY SURVEY

(*i*) In the beginning a survey of the rice soils from the various rice growing tracts of the Province was undertaken. Samples of soils to a depth of 18 in. were collected and their mechanical composition was determined and correlated with the yields of paddy. Results obtained showed the following:

(*a*) Under normal conditions fairly satisfactory yields of fine and medium quality rices are generally possible only from such soils whose clay content is 30—36 per cent at a depth of 6-12 in.

(*b*) Soils in which the percentage of clay at 6-12 in. and 12-18 in. depths exceeds 36 and 45 respectively, are usually incapable of giving satisfactory outturns with fine and medium varieties although for many of the coarser types of paddy they might be considered reasonably fit.

Results of chemical analysis have furnished the following important information from a practical point of view:

(*c*) It was found that in general the more the lime content of the soil in a particular tract the less was the yield of paddy.

(*d*) Crop growth has been found to be affected by the degree of acidity or alkalinity (i.e. the nature of soil reaction) present in the soil. Some crops are susceptible even to moderate changes in the reaction of the soil while others are comparatively more tolerant. In the case of the rice crop it was found that optimum outturns could be obtained if the reaction of the soil is either slightly acidic, or neutral, i.e. neither acidic nor alkaline. From the knowledge of the reaction of a particular soil we can thus adopt suitable methods of cultivation and manuring so as to increase or decrease either acidity or alkalinity to the desired extent.

In addition to the above findings, analytical data of fundamental importance relating to the important rice soils have been collected which will be very useful in deciding the nature of treatment to be accorded to a particular type of soil from a specific locality.

(*ii*) Attention was next directed to the intensive study of typical soils of the Chhattisgarh tract and for this purpose samples of soils were taken from the Bilaspur and Raipur districts. These samples were taken to a depth of 4·5 ft. and represented both cultivated and uncultivated soils. Results obtained showed the following important characteristics of the types of soils examined:

(*a*) Light soils (*matasi*). These soils are very poor in lime throughout the profile, i.e. to a depth of 4·5 ft. and contain a low proportion of clay and a high proportion of fine sand, the former generally increasing and the latter decreasing with the depth of the soil. These soils are usually slightly acidic in character.

(*b*) Medium soils (*dorsa I*). These soils contain a high proportion of clay and a low proportion of fine sand, and show a slightly alkaline reaction throughout the profile.

(*c*) Heavy soils (*kanhar*). These soils are similar to the somewhat heavy type of soils designated as *dorsa I* described above.

It will thus be seen that the data which have now been collectd regarding the lime content, reaction, phosphoric acid content and mechanical composition of the various types of soils will be very helpful in distributing proper types of coarse, medium and fine rices to suit specific soils, and suggesting manurial treatments and other methods of soil amelioration with due regard to the lime status and reaction of the soils in question.

LOSSES OF VALUABLE PLANT FOOD MATERIAL

In view of the fact that the action of rain and irrigation in removing various plant foods from the soil is intimately connected with plant growth an investigation into the losses of valuable plant food through leaching from different types of rice soils in the Chhattisgarh Division was carried out. Results obtained showed that as the period of leaching increases, there is a progressive increase in the amount of plant food lost from the soil, and that the loss of plant food from light soils is greater than that from heavy soils. These finds therefore suggest the necessity of applying at a time to light *matasi* soils, only small quantities of manures and fertilizers, and judicious use of irrigation water, so as to prevent their loss by leaching, and to maintain the natural soil fertility as far as possible.

Influence of fertilizers

Evolution of carbon dioxide under laboratory conditions from aerobic and water-logged cultures of the two main rice soils, e.g. *matasi* and *dorsa* receiving various manurial treatments was recorded daily for about a fortnight. The manures employed were, cattle-dung, *karanj* cake, ammonium sulphate, superphosphate, both singly and in combination. The main object of this work was to use the production of carbon dioxide as an index of soil fertility. Results obtained show the following:

(*a*) Most of the manures tend to be more ueful in *matasi* than in *dorsa* soil.

(*b*) For *dorsa* soil the treatments that are likely to be most effective are cattle-dung and *karanj* cake.

(*c*) The relative merits of the treatments—ammonium sulphate, superphosphate, and super plus cattle-dung—both under aerobic and water-logged conditions for *matasi* and *dorsa* soils appear to be almost identical.

Dispersion methods for the mechanical analysis of the rice soils

Twenty-one soils collected from various parts of the rice growing tracts of the Central Provinces were analysed by the International and Puri's dispersion methods and their results were compared. It was found that the former method gives a greater amount of clay and fine silt than the latter. The heavier soils were found to give a higher clay percentage with the Puri's method. The soils selected for the experiment had *p*H values varying from 5·4 to 7·6, organic carbon from 0·3 to 1·81, and calcium from 9 to 13·4 per cent. None of these could be correlated with the varying percentages of clay obtained in different soils by the two different methods.

Locally prepared bone-manure and superphosphate

Manurial experiments conducted by the Department have shown that rice responds very favourably to applications of phosphatic fertilizers and that the response is of the highest order when phosphates are used in conjunction with nitrogenous manures. The most important raw-material, namely bones, which contain a high percentage of phosphorus together with organic nitrogen in addition, though available in large quantities are at present not being utilized by the cultivators for manurial purposes. Experiments were therefore conducted to find out cheap and simple method of converting bones into a useful phosphatic manure. It was found that by the 'Alkali method' which is somewhat complicated and by the very simple and cheap method of 'Half charring' which can be practised by every individual cultivator under village conditions, a cheap phosphatic fertilizer can be prepared from bones in the villages.

The effect of the locally prepared bone-manure on the yield of paddy was studied by pot culture experiments, superphosphate being used for the sake of comparison. It was found that the crop responds markedly to the addition of phosphoric acid in the form of either bone-manure or superphosphate.

The economic application of P_2O_5 for paddy has been found to be 20 lb. P_2O_5 per acre. The comparative cost of 1 lb. of phosphoric acid from the bone-manure and superphosphate is found to be as. 0-2-0 and as. 0-9-6 respectively.

Preparation of compost

In order to derive full benefit from irrigation, improved varieties and the like, the soil must contain adequate quantities of organic matter. The usual available method for either increasing or maintaining the organic matter content of the soil is the proper utilization of animal and human excreta. In India a large proportion of the former is however employed as fuel and the latter is very little used as a manure due to caste prejudices and other conservative ideas. Methods are however available by which various vegetable waste materials can be converted into farmyard-like manure which when added to soils will considerably help to maintain their organic matter content. Suitable experiments have therefore been carried out to convert available vegetable waste materials like *karanj* (*Pongamia glabra*) leaves into artificial farmyard manure.

It was found that artificial manure could be successfully prepared from *karanj* leaves and other vegetable materials in shallow pits by adopting rain water method. Composts made according to this method from *karanj* leaves and paddy straw were tried against cattle-dung on the yield of paddy on the two main rice soils of Chhattisgarh. Results which have been statistically examined show that the composts give as good yields of paddy as those given by cattle-dung manure.

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